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REPORT ON OCEAN DUMPING RESEARCH AND DEVELOPMENT ATLANTIC REGION 1980-1981

(PROCEEDINGS OF A WORKSHOP, JAN. 27-28, 1982, HELD AT BEDFORD INSTITUTE OF OCEANOGRAPHY)

Surveillance Report EPS-5-AR-82-1

Atlantic Region

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REPORT ON OCEAN DUMPING RESEARCH AND DEVELOPMENT ATLANTIC REGION 1980-1981

(Proceedings of a Workshop, Jan. 27-28, 1982, held at Bedford Institute of Oceanography)

Edited by

C.D. MacGregor* and G.A. Packman**

for

Regional Ocean Dumping Advisory Committee (Atlantic)
[RODAC (Atlantic)]

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Environmental Protection Service
and
Department of Fisheries and Oceans

Environment Canada
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ABSTRACT

A workshop was held January 27 - 28, 1982, to review the results of research conducted under the auspices of the Ocean Dumping Research Fund in fiscal year 1980/81, and to discuss priority research areas for 1982/83 funding. Papers related to Ocean Disposal but not funded by the Ocean Dumping Research Fund were also presented. A panel discussion dealing with the subject of land versus ocean disposal of contaminated marine sediments was held. Specific discussions of research priorities at Dalhousie and Saint John, New Brunswick were also held along with a discussion of national research priorities.

RESUME

On a tenu, les 27 et 28 janvier 1982, un atelier afin d'examiner les résultats de recherches effectuées sous les auspices du Fonds de recherche sur l'immersion des déchets en mer au cours de l'année financière 1980-1981 et pour discuter des domaines de recherche qui devraient se voir accorder la priorité, en 1982-1983, en ce qui a trait à l'octroi de fonds. Des études portant sur l'immersion des déchets en mer, mais non financées par le Fonds de recherche sur l'immersion des déchets en mer, ont été également présentées. Une table ronde a tenté de déterminer s'il est préférable d'enfouir les sédiments marins contaminés sur terre ou de les immerger en mer. Des discussions précises portant sur les priorités de recherche à Dalhousie et à Saint-Jean (Nouveau-Brunswick) et une discussion portant sur les priorités de recherche nationales ont également eu lieu.

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1. OPENING REMARKS

Hugh. A. Hall
Director, Marine Environment Branch
Environmental Protection Service
Environment Canada

Introduction

I want to extend a personal welcome to all of you this morning. I am pleased to see many people in the audience whom I either know or recognize, and I am pleased to see that most of those contacted to attend this workshop have, in fact, been able to attend.

My initial affiliation with ocean dumping in the Atlanic Region goes back to the years previous to the promulgation of the Ocean Dumping Control Act, and for several years following. In many ways we did not suspect then the role the Act would eventually play in the activities of some goverment agencies, industries, and citizens in this region.

After a brief separation from the administration of the Act, I am pleased to be affiliated with it again, and to be associated because of it with all of you.

With expanding environmental awareness has come the realization that the capacity of the marine environment to accept the waste products of man's activities is not infinite. Increasing activity in, and uses of, the marine environment will lead to even greater stresses and possibly to decline in environmental quality with resultant health, economic, and social implications.

Fortunately, governments are becoming increasingly sensitive to the importance of ocean resources and to the need to preserve and enhance marine environmental quality. What they appear to have been slower to appreciate is the difficulty of preserving and enhancing the quality of the marine environment in the face of competing, and contradictory, policies and priorities.

One area in which this difficulty presents itself is, obviously, ocean dumping of waste materials.

On the one hand there is the priority for economic growth which is usually expressed by industrialization; and on the other hand there is the value and significance of the marine environment as part of our total environment and as a sustainable source of food.

Where success has occurred in resolving marine environmental quality problems, it can frequently be attributed to understanding the cause-effect relationships, to effectively translating scientific knowledge into public policy, and to motivation which comes from public awareness of the problem.

In implementing environmental laws in the face of competing economic, social, and environmental priorities, regulators are increasingly seeking more information on ecological consequences of trade-offs to guide them in many issues they are confronting. As we all know, the ultimate consequences of decisions have sometimes only been understood after a considerable period of time.

Progress in this matter requires improvement in our ability to predict the consequences of marine discharges, and our ability to detect, measure, and understand the significance of damage or benefit after it has occurred.

Improved predictive capability will depend upon an integrated approach to the use of research studies, models, and field investigations. Predictions must then be complemented by improved monitoring capability which can detect actual impacts, and serve as a feedback mechanism with respect to the accuracy of our original predictions, and the adequacy of our regulatory actions.

Pressure can be expected to mount in the future to use the marine environment in the resolution of terrestrial and atmospheric environmental quality problems. Already the U.S.A. is seriously considering relaxing controls on the marine disposal of low-level radioactive wastes.

Equally important will be the consideration of whether excessively stringent controls on marine activities may impose unnecessary costs or greater burdens on some other sector of the environment. The need for better information about the ecological consequences of activities, whether in the ocean or on land, will be even greater in the future than it is today.

The competing priorities of energy security and marine natural resource sustainability face us in the Atlantic region here and now. We face conflicts due to the need to protect, manage, and harvest fishery resources, the need to allow increased ocean transport of hazardous products, and the need to explore and develop seabed energy and mineral resources. It is not likely that any of these activites can be carried on at the economically optimum level without significantly affecting others.

A classic conflict in this region with which many of you will be familiar is the need to keep small fishing harbours open through dredging so that fishing boats can land their catches and seek shelter, while at the same time trying to avoid compromising the quality of the marine environment by dumping contaminated spoil where it could jeopardize a fishery and the livelihood of fishermen.

The pace of these and other human activities implicating the marine environment in this region is accelerating and is outdistancing our rate of acquiring and understanding relevant scientific information. We are increasingly forced to make decisions which affect economic development, or which affect marine environmental quality, without an adequate understanding of the consequences of these decisions over the long term.

Agencies and individuals, many of which are represented by you here this morning, will have to combine forces, cooperate and consult, even more than we have previously, in order to marshal all relevant information to make the best judgments when decisions are to be made which risk the marine environment. The risks can and will no doubt be calculated; however, as has been said elsewhere in relation to arguments of acceptable risk analyses: it's not the odds, it's the stakes!

Development will occur; the marine environment will be affected. Hard decisions will have to be made with the available information, with the available opinions, and with the available money.

We know that in many cases we can not afford to make mistakes, but we also know we can't afford to control in absolute terms.

We must focus more of our resources on understanding key processes in the marine environment, weak or susceptible links, and critical cause-effect relationships. Economic pressures and development pressures are going to be undeniable in this region; time for in-depth analysis and contemplation will be limited; compromises will be demanded.

The message I leave you with this morning is that we need your help to administer the Ocean Dumping Control Act fairly, honestly, and practically in the face of competing priorities and undeniable pressures. We have to be prepared to compromise with reasonable knowledge of the trade-offs involved, but we also need to know when to say no.

Closing

You can see from the agenda for the next two days that several of our regional problems are open for discussion. Although absolute answers are unlikely, the collective considerations of this group are bound to increase the available information, our mutual understanding of the problems, and the opportunities for pragmatic solutions.

With that, I thank you for your attention, and turn you over to your Chairman, Alan McIver.

2. PRESENTED PAPERS

2.1 THE EFFECT OF SUSPENDED AND DEPOSITED SEDIMENT ON THE BEHAVIOR OF THE AMERICAN LOBSTER, Homarus americanus

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Introduction

There is limited information on the effects of either suspended or deposited sediment from dredging operations on the American lobster, Homarus americanus. Potential stresses to this important commercial species are known to include uptake of heavy metals or other toxic substances from contaminated dredge spoils, and damage to gill structures and integument of larval stages under high concentrations of suspended sediment (Cobb, 1972). To date there has been little consideration of the behavioural responses of lobsters to deposited or suspended dredge spoils. If adult lobsters avoid suspended sediment in high concentration, dredging or dumping could have a deleterious, though probably short-term, effect on local fisheries. In the dump site zone, changes in substrate type due to accumulation of spoils could render an area altogether unsuitable for lobsters.

Juvenile American lobsters may resemble their European counterparts (H. gammarus), in that they inhabit grounds that are separate to those occupied by their adult conspecifics (Howard, 1980). Hence criteria for dump site selection with regard to lobsters in the Canadian maritime provinces should not be based solely upon the presence or absence of commercial sized animals. The dredging or smothering of 'nursery areas' occupied by juvenile lobsters could have serious consequences to future recruitment into a commercial fishing area. Furthermore, as Stage IV lobster larvae usually prefer a gravel substrate to one of sand or mud, and may delay molting to the epibenthic fifth stage until "favorable (rocky) conditions are reached" (Cobb, 1968), alteration of substrate from dumping operations could affect larval settlement patterns.

Our project, conducted from January to March 1980, was essentially a preliminary study to evaluate equipment designs and techniques for investigating lobster behavior in response to both suspended and deposited sediment, and to study the effects of continuous exposure to high concentrations of suspended sediment.

The main emphasis of the study was on the substrate selection of Stage VII to X juveniles when offered a choice between clear gravel and silt-clay deposited over gravel, such as might be encountered in a dump zone (Pottle and Elner, in press). This experiment and two others, on avoidance of and long-term exposure to suspended sediment, are here described.

Materials, Methods, and Results

Substrate preference

Thirty-two early-stage juvenile lobsters of 9 to 15 mm carapace length were each introduced to a tank compartment containing equal quantities of clear unsorted gravel and silt-clay over gravel (Figure 2.1). Time spent on each substrate and site of shelter selection during the 15 min after introduction, and subsequent burrow location over a 5- to 9-day period, were used as indicators of substrate preference.

The number of trials in which proportion of total time (15 min post-introduction) on gravel exceeded 0.50 ($p = 25/32 = 0.78$) was significantly higher than that expected if there was no preference between substrates (t-test, $p < 0.01$). Twenty-nine (90.6%) of the animals selected a shelter within 15 min after introduction. Significantly more of these (24) selected a shelter site in gravel than in silt-clay (chi-square test, $p < 0.01$). The remaining five lobsters excavated burrows in silt clay, but only adjacent to or beneath solid structures such as tank walls or protruding stones. In 242 post-introduction period sightings of lobsters in shelters, 194 animals were in gravel. This number is significantly higher than that expected (121) if there is no preference of gravel over silt-clay for shelter location (chi-square test, $p < 0.005$).

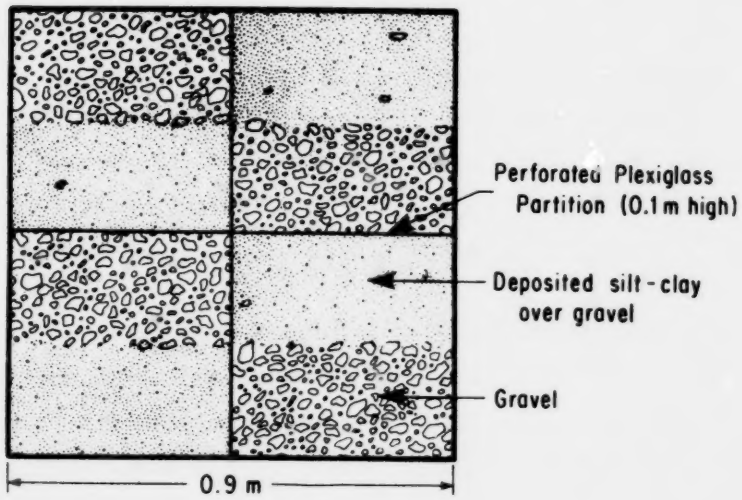


Figure 2.1

Plan view of tank used to test substrate preference by juvenile Homarus americanus

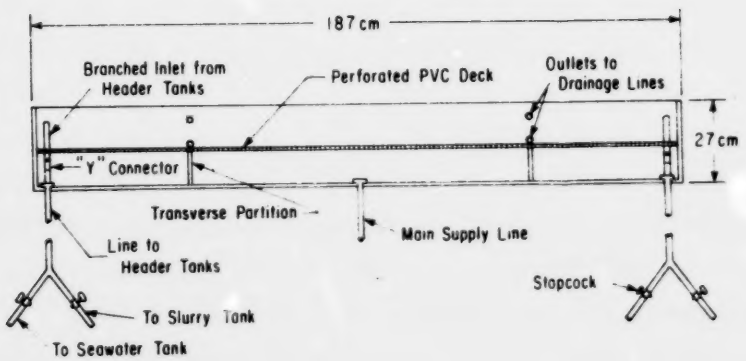


Figure 2.2

Apparatus used to determine avoidance behaviour of lobsters to suspended sediment.

Avoidance experiment

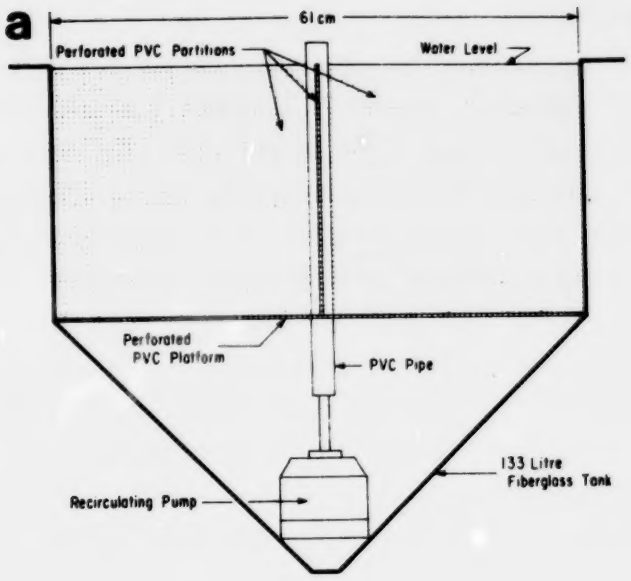
Adult H. americanus (450 g wet wt) were tested for avoidance of suspended Miramichi Bay sediment in the apparatus illustrated in Figure 2.2. A turbid zone could be created in either end of the apparatus by the introducion of slurry from a header tank. Suspended sediment concentration increased steadily and trials were limited to 10 min duration due to gradual diffusion into the central area of the tank.

Test subjects, including both native lobsters and animals which had been held in high concentrations of suspended sediment for 9 to 10 days, were placed singly in the centre of the tank and allowed free vertical inlets. Lobsters invariably came to rest in one end of the tank and were immobile for at least 10 min before slurry was substituted for the seawater control, at the same inflow velocity. The activity of the lobster was monitored for 10 min after introduction of the slurry.

There was one case of avoidance by a native animal in 23 low concentration trials ($\overline{X}$ = 74.2 mg sediment/L) and no avoidance in 16 high concentration trials ($\overline{X}$ = 197.8 mg sediment/L). Seventy percent of the lobsters did not exhibit locomotor behavior but a slight increase in the first antennule 'flick' rate was often observed after the sediment plumes appeared behind the animal. The remaining lobsters oriented to and moved through the sediment plumes and one lobster then left the turbid zone. Lobsters within the turbid zone were completely obscured within 5 min although water depth was only 12 cm.

High concentration exposure

Twenty adult and 32 juvenile lobsters (Stages VI to X) were exposed to high concentrations of Miramichi Bay sediment for 9 to 10 days while an equivalent number of control animals were held under similar conditions in seawater only. Animals were confined in separate compartments in closed system tanks (Figure 2.3) aerated by airstones. Sediment was added to the treatment tanks in quantities of 10 g/L of tank capacity, and was recirculated by water-cooled electric pumps. The pump and circulation system proved incapable of keeping all sediment suspended, and preciptated



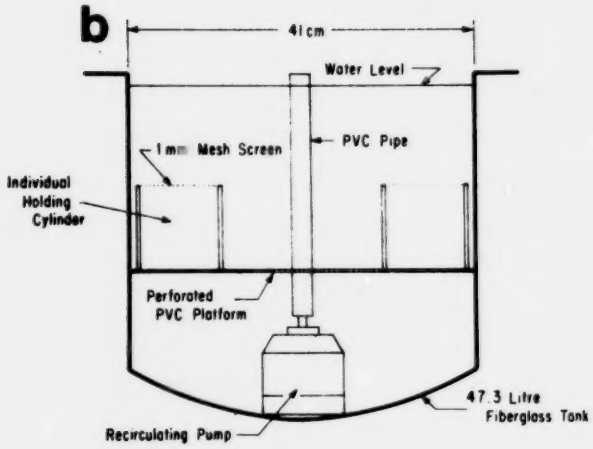


Figure 2.3

Apparatus used to determine long-term effects of suspended sediment on lobsters; a) 133 L tank, b) 47 L tank.

material was resuspended by stirring twice daily. Concentration was highly variable and ranged from 56 to 1331 mg/L, before and after stirring, in the 133-L tanks (each holding four adult lobsters), and from 34 to 1455 mg/L in the 47-L tanks (each holding eight juveniles). The operation of the pumps raised the water temperature from 11 - 12°C to 17 - 20°C within 8 hr of the beginning of each test series. Despite this additional stress there was no significant difference in mortality between control and treatment groups. All adult lobsters survived, and two juveniles died in both control and treatment groups. One of the treatment deaths was due to an interaction between two juveniles that escaped from their compartments. The other treatment juvenile died within 36 hr of molting although another that molted one day earlier survived. A third juvenile molted successfully 14 days after the experiment terminated.

Examination of the dead animal revealed no deformities of appendages or exoskeletal damage. However, fine particles of sediment were present in all joints and there were heavy deposits among the feeding appendages and on the ventral surface. Large and small sediment particles were present in the branchial cavity but the gills did not appear unduly clogged.

Discussion

We believe that H. americanus juveniles choose gravel substrate over silt-clay because the latter lacks readily available shelter, and because evacuation and maintenance of burrows in silt-clay may be difficult in the absence of supporting structures such as embedded stones. The known presence of H. americanus juveniles in the gravel and boulder substrates of inshore areas (R.W. Welsford, pers. comm.) warrants concern regarding the possible detrimental effects of ocean dumping on lobster 'nursery' areas. Assuming that juvenile lobsters prefer gravel to silt-clay in field situations, then, in an area where dumping of dredge spoils occurs, smothering of gravel substrate may result in increased spatial competition among lobsters for shelter in remaining gravel habitat. Adverse results of such competition could include increased mortality due to predation, caused by a decreased availability of suitable shelters and subsequent increased vul-

nerability to predators. In addition, lobsters could exhibit a decreased growth rate from crowding, as observed in the laboratory by Cobb and Tamm (1974) and Stewart and Squires (1968).

Although the results of the other experiments are preliminary in nature, it would appear that most adult H. americanus will tolerate highly turbid conditions for at least 10 min, and that lengthy exposure to high concentrations of suspended sediment does not result in direct mortality.

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2.1.1 Investigation into the Direct and Indirect Effects of Ocean Dumping on Lobster Ecology and Habitat with Special Reference to Juvenile Lobsters (Status Report)

R.W. Elner

Pilot laboratory studies in 1980 determined that juvenile and adult lobsters appear tolerant to high concentrations of suspended sediments and juveniles demonstrate a perference for gravel compared to silt/clay substrate. It was hypothesized that such behavior in the field might lead to movement away from dump zones and increased competition for preferred substrates with resultant increased mortality and decreased growth rates.

We have determined to test our hypotheses in the field with a study of direct and indirect effects of dumping on juvenile lobsters over a 12-month post-dump period. Previous surveys by Invertebrates and Marine Plants Division have located high densities of juveniles lobsters in gravel/sand substrates in inshore areas; these areas have been loosely described as 'nursery' areas. Present ocean dumping policy would be to avoid dumping on commercial lobster ground, but we have been concerned that dumps might occur on 'nursery' areas which tend to be separate from commercial grounds.

In the present investigation sediment will be dumped onto a pre-surveyed juvenile lobster 'nursery' area in Halifax Harbour. SCUBA divers will assess the impact of the dump on the 'nursery' as well as site macrofauna and flora over a 12-month period. A similar 'nursery' in the same locale will be designated as a control and be monitored throughout the investigation. A contract for $7500 involving site selection, pre-dump survey, and dumping has been awarded to the Richard W. Welsford Research Group Limited. After the contract, monitoring of dump and control sites will be carried out by divers from the Invertebrates and Marine Plants Division. To date, site selection and mapping has been completed and a full pre-dump survey is currently underway. The controlled dumping is scheduled for February.

Of particular interest will be long-term changes in juvenile lobster density, population structure, and behavior as a result of the dumping. As the dumping will likely create a mozaic of different physical conditions, special attenton will be paid to where on the site lobster colonization occurs in relation to sediment depth and substrate type.

2.2 POSSIBLE IMPACT FROM DREDGING AND SPOIL DISPOSAL ON THE MIRAMICHI BAY HERRING FISHERY

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The detailed results of our work on this subject may be found in Messieh et al. (1981) (Can. Tech. Rep. Fish. Aquat. Sci. 1008, available from Marine Fish Division, BIO). It was entirely fortuitous that the field and lab work were completed before the dredging activity began on April 26, 1981. The actual reason for this timeliness was that the dredging start was delayed for two years from the originally proposed date. This facilitated incorporation of research derived information into the regulatory process.

The Miramichi estuary and outer bay are the sites of an important commercial fishery for herring worth about $0.7 million in 1979. The adult herring return each year to the same spawning ground and are caught in fixed gillnets erected for an approximately one-month-long fishing season. The gillnets are set near the Baie Ste. Anne and Escuminac wharves which is also the area of highest herring spawning density.

The basis for our recommendation resulted from lab work which showed that:

- sediment deposited onto developing herring eggs causes increased mortality due to a smothering effect inhibiting circulation of oxygenated water around the eggs.

- suspended sediments were shown to inhibit the feeding success of herring larvae. Since herring larvae are visual feeders, the increased turbidity interferes with their ability to see prey organisms, resulting in fewer successful captures.

- juvenile herring avoided areas high in suspended sediments. Both juveniles and possibly adults may avoid fixed gillnets subject to high suspended solids levels. Thus individual gillnets nearest the dredging or dumping may face reduced catches because herring avoid them.

These results are, in general, applicable to other locations where there is a herring spawning ground and fishery. It would be preferable to have threshold effects determined in field experiments to improve the accuracy of our predictions regarding the potential negative effects on the fishery.

2.3 AQUATIC RESOURCE MANAGEMENT AND MARINE RESEARCH

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Abstract

The functions of RODAC managers and researchers are critically examined. It is suggested that managers should adopt long-range planning to remit and deal with any pertinent factors that affect multiple-use of aquatic ecosystems. As an example of the approach suggested, resource problems in the Saint John Harbour are discussed.

What is to be Managed?

The unit to be managed usually has spatial limits. Ideally, the area should be as large as possible, e.g., the Bay of Fundy and its watershed. Practical considerations will usually dictate smaller sizes, e.g., Saint John Harbour, which will be used throughout this discussion as a model.

What are the Management Goals?

For purposes of discussion, the management goals are considered to be "The optimization of benefit to all who use Saint John Harbour as a renewable natural resource." The following is a short list of the uses:

- passageway for migrant fish, e.g. salmon,
- commercial and recreational fishing,
- water abstraction for industrial cooling purposes,
- industrial and municipal waste disposal assimilation, and
- commercial and recreational shipping.

Is the Present Management System Effective?

Management decisions often come too late, or not at all, for the potential benefits to accrue. This results from the currently used reactive style that managers have adopted.

Can the Management System be Improved?

I believe that two fundamental changes are required to improve resource management:

- by considering resource management in context, rather than fisheries concerns versus dumping practices in isolation, and

- by changing to a long-range planning style of management which considers a range of options in advance of need. Such an approach would require a heavy investment in engineering, industrial, oceanographic, and biological technical expertise.

What is to be Researched?

The questions to be asked and which require technical knowledge flow logically from familiarity with the long-range plans for the Saint John Harbour.

Is the Present Dumping Research Useful?

Because the right questions are not necessarily asked, much ocean dumping research is wasted because it cannot result in corrective management actions. The currently asked questions result from the reactive nature of management and may give too much weight to vested interests, such as fishermen. That is not to say that fishermen do not have a problem in the harbour, just that it seems unlikely to be primarily caused by dumping practices.

How Can Research Related to Dumping be Improved?

- The right questions must be asked.

- It is the research worker's responsibility to form multidisciplinary groups inclusive of engineers and industrial planners, as well as physical and biological scientists, who are capable of resolving the pertinent questions of the near future.

- It is a management responsibility to find ways and means of adequate funding for a sufficiently long period to ensure in-depth work of high quality.

Conclusion

What I have proposed in this discussion is that any resource management action will be wasted unless we take a good, hardnosed look into the future, side-by-side with the industrial planners, so that we can see what kind of 1984 or 2000 is in store for us. It will then be possible to anticipate potential resource use conflicts before they arise and research economically viable alternatives that have the least harmful multiple-use resource conflicts. Resource managers will then be part of a planning team involved in the orderly development of an industrial/fisheries centre, such as Saint John.

2.4 NOTES ON BIOAVAILABILITY OF CADMIUM AND LEAD TO A MARINE CRUSTACEAN THROUGH FOOD AND WATER

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Most marine organisms normally can adapt themselves to natural variations in trace metals levels in the aquatic environment. However, bioaccumulation of trace metals by marine organisms is at times of serious concern because high levels of trace metals in commercial species may create problems for human consumption and may produce detrimental effects on fishery resources.

Cadmium (Cd) and lead (Pb) occur in trace amounts in ocean waters but are of special significance because of their high potential for bioaccumulation in marine organisms, especially in invertebrates. Figure 2.4 depicts the cadmium cycle in the marine environment. We have earlier studied Cd uptake by marine invertebrates from naturally contaminated and from spiked sediments (Ray et al., 1980a, 1981), and from water (Ray et al., 1980a,b). Physiochemical characteristics controlling sorption of Cd at the sediment/water interface have been studied (Ray and McLeese, 1980a). Bioavailability of Cd to marine organisms has been reviewed (McLeese, 1981; Ray and McLeese, 1980).

Bioaccumulation can occur either directly from the water by absorption through the body surface including gills or indirectly from food.

The mechanisms of uptake, disposition, and elimination of the metal by invertebrates have been poorly understood. A number of studies have been reported on uptake of Cd through water (Dethlefson, 1977/78; Thurberg et al., 1977; Ray et al., 1980b). However, uptake of Cd through food has been studied only with euphausiids (Benayoun et al., 1974).

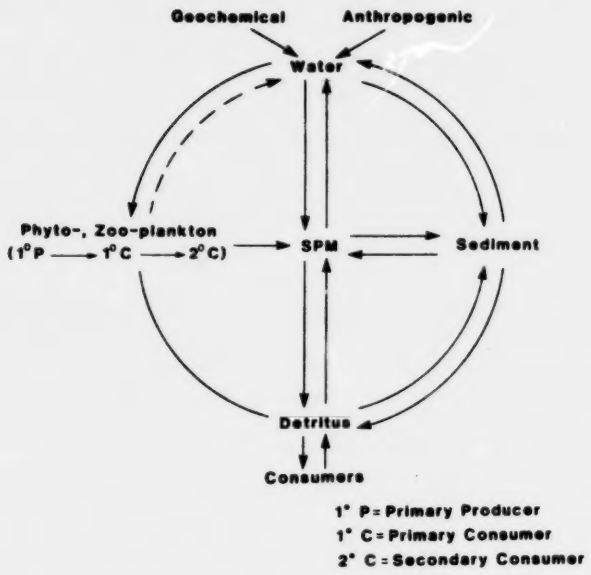

Figure 2.4

Cadmium cycle in the marine environment

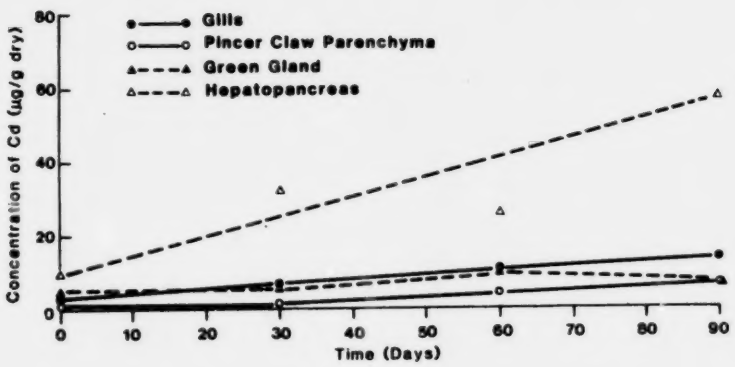

Figure 2.5

Cadmium uptake from water by different lobster tissues at 7µg Cd/L.

We have studied relative uptake routes and disposition of Cd in the American lobster (Homarus americanus) for exposure to Cd in water and in food.

The uptake from water was studied in static systems. The lobsters were exposed to 7 and 21 ug Cd/L for 90 and 60 days, respectively. Excretion was not studied.

For the study of uptake from food, lobsters were held individually in a flow-through system. The food contained Cd-contaminated Belledune lobster hepatopancreas (Ray et al., 1981) and minced fresh flounder and herring meat. The lobsters were fed at the rate of 5% of their body weight per week, and were fed on alternate days for 60 days. To measure excretion, the remaining lobsters were divided into two groups, one being fed uncontaminated food and the other starved for 60 days.

The uptake pattern of Cd^{3} from water by different tissues at 7 and 21 ug Cd/L exposure concentrations is shown in Figures 2.5 and 2.6, respectively. The gills are the primary deposition sites in both cases, although there is a sudden increase in rate of Cd uptake in both gill and hepatopancreas of the animals exposed to 21 ug Cd/L after 45 days. In contrast, most of the cadmium administered through food (Figure 2.7) is deposited in the hepatopancreas.

During excretion, the cadmium concentration in the hepatopancreas of the unfed animals increases at the same rate as during the uptake phase but there is a decrease for the fed animal group (Figure 2.8). However, when the amount of lipid lost from the hepatopancreas during starvation or gained during feeding is accounted for, it is observed that the total amount of cadmium in the hepatopancreas remains the same for both animal groups over the 90-day excretion phase.

As observed earlier (Ray et al., 1981), Cd in the hepatopancreas accounts for 90% of the total amount of cadmium in the tissues that were analyzed.

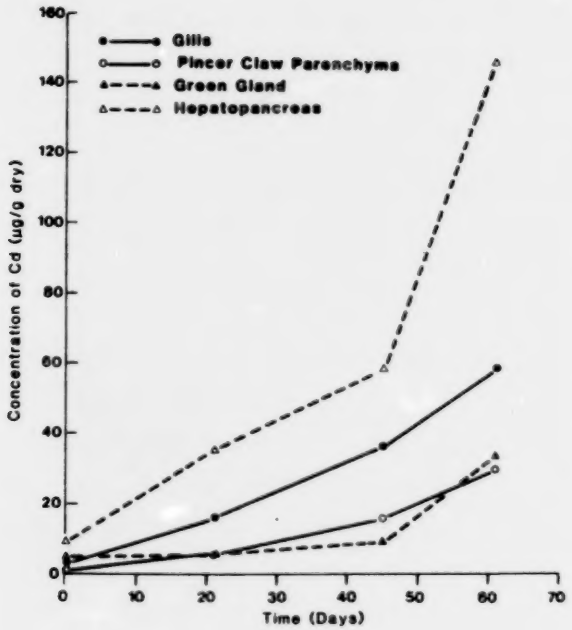

Figure 2.6
Cadmium uptake from water by different lobster tissues at 21 µg CD/L.

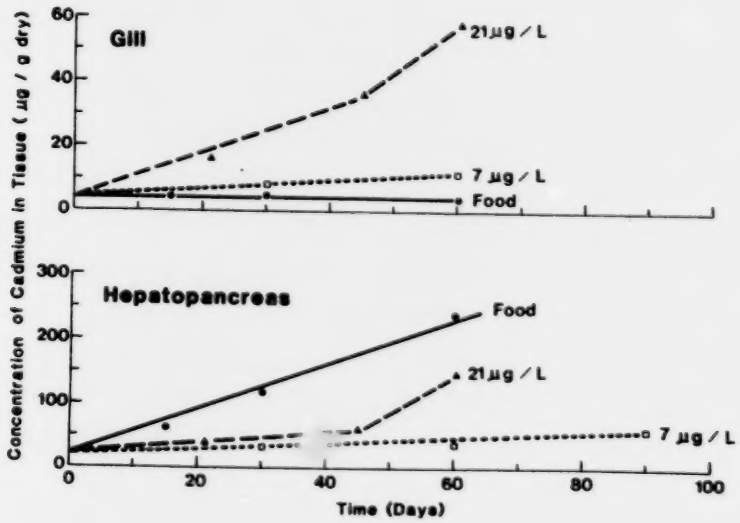

Figure 2.7
Cadmium uptake from spiked food.

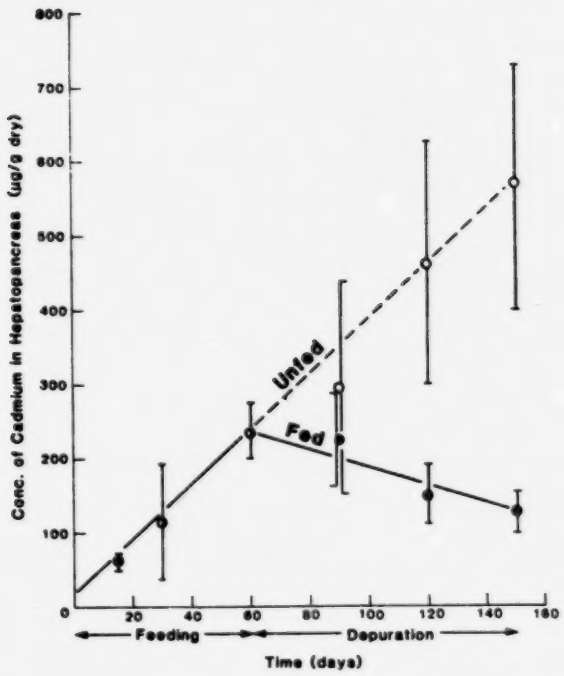

Figure 2.8

Cadmium uptake by fed and unfed lobsters

Definitive conclusions could not be drawn for uptake of lead administered through food along with cadmium, either because of the very low level of lead in the food or possibly because lobsters may not accumulate lead to any great extent.

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2.5 LABORATORY EXPERIMENTS TO ASSESS THE BIOACCUMULATION OF CADMIUM FROM MARINE SEDIMENTS

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Introduction

The Canadian Ocean Dumping Control Act sets the acceptable level of cadmium in sediments destined for ocean disposal at no more than 0.6 ppm. After many instances of receiving requests to dispose of sediments containing cadmium in excess of this amount, a protocol was developed to provide a means of assessing potential environmental damage that might result if disposal in the ocean was permitted. Two of the four requirements of this protocol involved laboratory bioassays to determine if the cadmium could be bioaccumulated by a marine organism.

A static marine benthic bioassay using Macoma balthica had been developed for EPS (Sharp, 1977) and the method was modified only slightly with use since then. However, after using this method to assess bioaccumulation from 12 different sediments that had cadmium levels in excess of 0.6 ppm, bioaccumulation of cadmium by Macoma was never convincingly demonstrated (Table 2.1). Doubts were expressed about the method, the choice of animal, and the limit of 0.6 ppm of cadmium. Because of these doubts, longer term bioassays with nine different marine organisms were conducted to further investigate bioaccumulation of cadmium from marine sediments.

Materials and Methods

Samples of three sediments were obtained with the assistance of the EPS Ocean Dumping Section. The sediments were from Dalhousie West Bay and Belledune Harbour, New Brunswick, and Grand Desert Beach, Nova Scotia. Total cadmium was measured on the sediment samples at 0, 30, 60, and 100 days.

Table 2.1

SEDIMENTS TESTED FOR BIOACCUMULATION OF CADMIUM BY MACOMA BALTHICA. NO BIOACCUMULATION DEMONSTRATED EXCEPT FROM CAP ST. LOUIS SEDIMENT

SEDIMENT	DATE	TOTAL CADMIUM IN SEDIMENT (UG/G)
St. Thomas	1979	0.95
Escuminac Inner	1979	1.2
Escuminac Outer	1979	0.6
Miscou	1979	0.7
Cap. St. Louis	1979	1.26
Shippegan South Harbour	1979	0.65
Blue Cove	1979	1.6
Escuminac Inner	March 1980	0.99
Dalhousie Cargo Wharf	August 1980	1.65
Dalhousie Public Wharf	August 1980	2.85
Green Point	July 1980	1.4
Canso New Wharf (Inner)	October 1980	1.3

In the laboratory, 85 L of sediment were placed in a 90 x 90 x 40 cm fibreglass tank to form a 10-cm layer on the bottom of the tank. The overlying water was approximately 25 cm deep and was a mixture of filtered and unfiltered Bedford Basin seawater continually flowing at about 3 L/min to provide replacement of the overlying water every 2 hr. The test solutions were lightly aerated. Temperature was ambient for Bedford Basin seawater.

The test organisms used are listed in Table 2.2 along with their collection site. The nine organisms were placed in the test tanks on June 27, 1980. A mesh basket isolating one section of the tank contained the algae and mussels, thus protecting them from being consumed by sea urchins and starfish, respectively. The other animals were all allowed total freedom of movement in the tank. A continual supply of algae and mussels was kept outside the segregated portion of the tank to supply food for the sea urchins and starfish. Temperature, flow rates, dissolved oxygen, pH, and test organism mortality were checked daily.

Samples of tissue from the nine organisms were collected at the start of the test and after 30 days, 60 days, and 100 days exposure to the sediments. Before tissue samples were collected, all animals were placed in running seawater without sediment for 48 hr to allow for depuration of sediment from their alimentary tracts. Soft tissue was removed from the sea urchins, mussels, periwinkles, and the two types of clams. Whole organisms were collected for the algae, polychaete, starfish, and sand shrimp. The tissue samples were rinsed with distilled deionized water and placed in acid-rinsed glass jars and kept frozen until analyzed for cadmium by flameless atomic absorption spectrophotometry using a Perkin Elmer HGA 2100 (O. Vaidya, pers. comm.).

Results

The cadmium concentrations in the sediments are given in Table 2.3. The Grand Desert, Dalhousie West Bay, and Belledune sediments contained 0.11, 1.43, and 58 ug/g of cadmium, respectively.

Table 2.2

MARINE ORGANISMS USED IN BIOACCUMULATION EXPERIMENTS

COMMON NAME	SCIENTIFIC NAME	COLLECTION SITE
Algae	*Fucus disticus*	Bedford Basin
Blue mussel	*Mytilis edulis*	Bedford Basin
Clam	*Mya arenaria*	Grand Desert
Clam	*Macoma balthica*	Grand Desert
Periwinkles	*Littorina littorina*	Grand Desert
Polychaete worm	*Nereis* spp	Grand Desert
Sand shrimp	*Crangon septimspinosa*	Lawrencetown
Sea Urchin	*Stronglycentrotus droebachiensis*	Bedford Basin
Star Fish	*Asterias vulgaris*	Bedford Basin

Table 2.3

CONCENTRATION OF CADMIUM IN SEDIMENT SAMPLES (UG/G)

SEDIMENT	0 DAYS	30 DAYS	60 DAYS	100 DAYS	MEAN ± S.D.
GRAND DESERT	0.09 0.15	0.1	0.1	0.14	0.11 ± 0.02
DALHOUSIE	1.07 2.00	1.7	0.6	1.81	1.43 ± 0.52
BELLEDUNE	47.8 76.0	5 7	55	55	58 ± 9.1

Dissolved oxygen concentrations in the overlying water ranged from 68% saturation to 100% saturation over the 100-day experiment and pH ranged from 7.5 to 8.3. The temperature ranged from 7.5°C when the experiments were started in June to a peak of 19°C in September (70 days into the experiment), and back down to 13°C when the experiments terminated in October.

The results of cadmium analysis on the tissue samples showed that M. balthica exposed to Belledune sediment significantly increased the amount of cadmium in soft tissue as compared to those clams exposed to Grand Desert and Dalhousie sediments (Figure 2.9). After 30 days the cadmium in the tissue had increased from 0.03 µg/g (wet weight) initially to 0.6 µg/g (wet weight). At 60 and 100 days, the cadmium level remained similar in the tissue.

A similar pattern was seen by Mya arenaria (Figure 2.9). After 30 days, the cadmium concentration in the soft tissue was 0.65 µg/g wet weight. After 100 days, the mean Cd concentration was 0.77 µg/g wet weight.

For the other seven organisms, no such pattern of bioaccumulation was evident (Figure 2.10). There was considerable variation with the data but there were no significant differences beween animals in the three different sediments.

Discussion

For the first time in our laboratory, Macoma balthica demonstrated bioaccumulation of cadmium. The accumulation occurred within 30 days but only from a highly contaminated sediment (58 ppm of cadmium). The present 30-day bioassay with M. balthica appears adequate to demonstrate cadmium uptake from contaminated sediments.

With longer exposure the cadmium level in M. balthica exposed to Belledune sediment did not increase above the 30-days level. A state of equilibrium seemed to be achieved by 30 days so there may be no point in continuing exposures past that point. Ray et al. (1981), using M. balthica

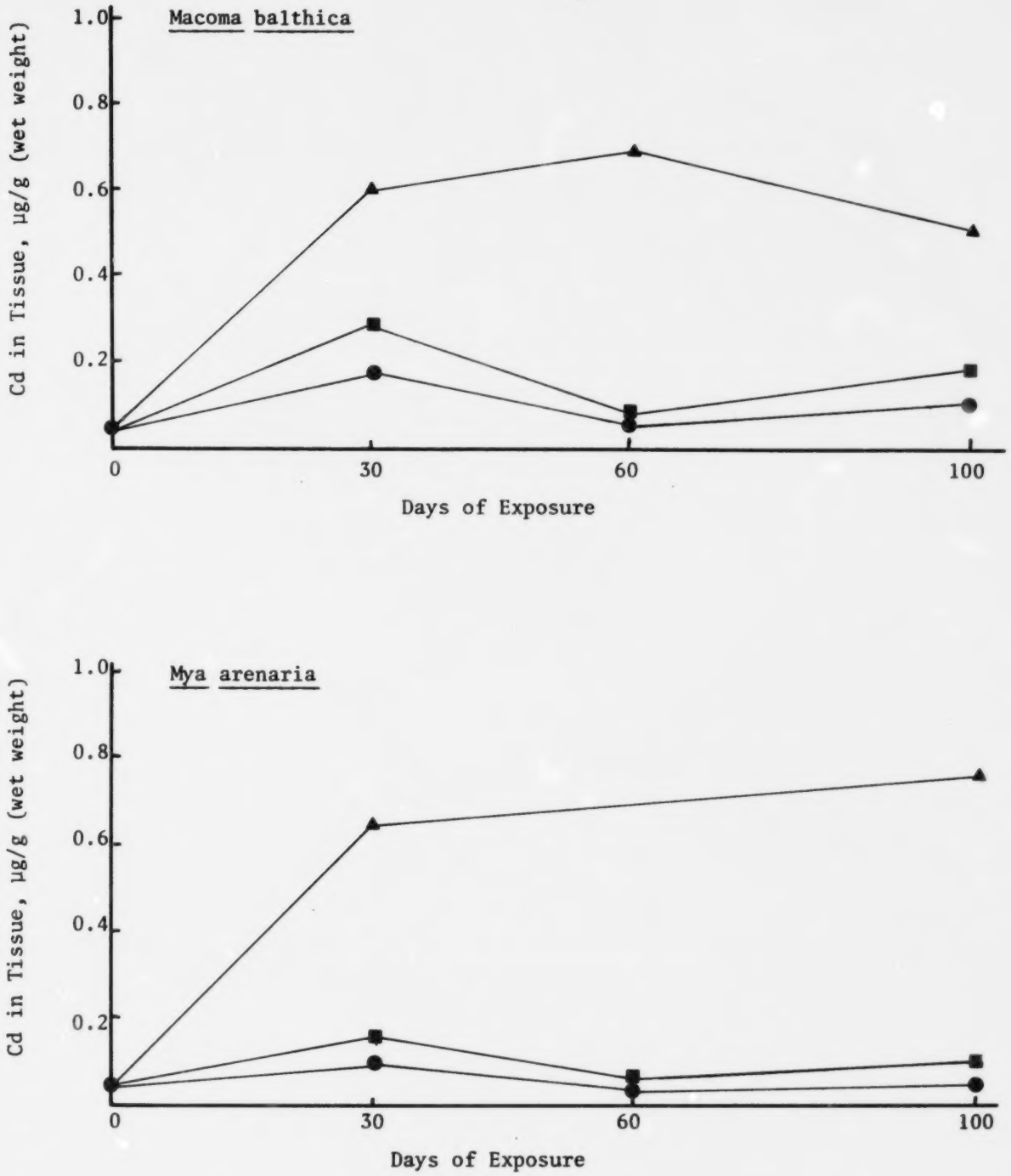

Figure 2.9

Cadmium in soft tissue of two bivalves after exposure to three sediments - Belledune (▲), Dalhousie (■) and Grand Desert (●).

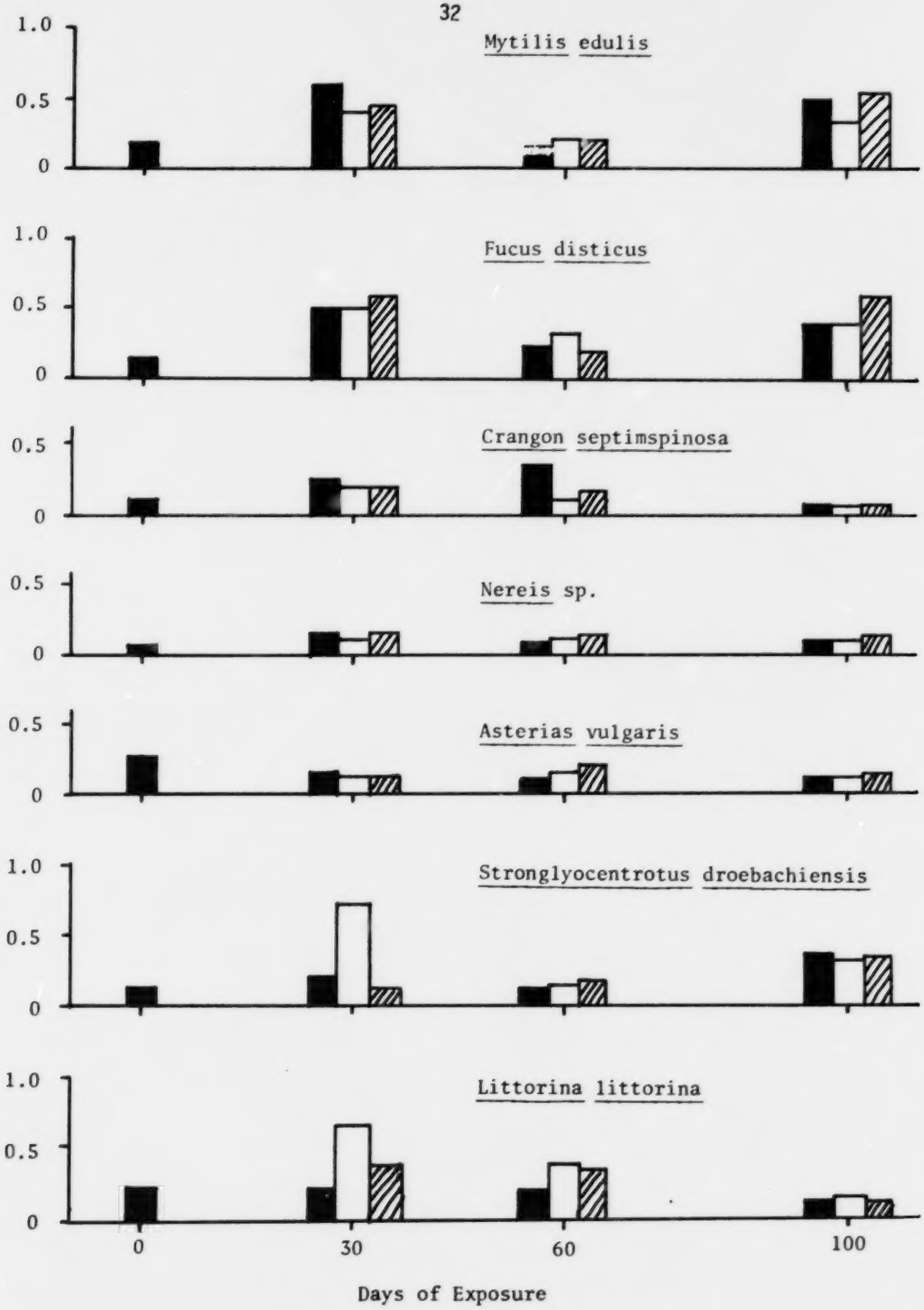

Figure 2.10

Cadmium in tissue of organisms to three marine sediments - Belledune (▨), Dalhousie (▭) and Grand Desert (▬).

in 30-day experiments, showed bioaccumulation of cadmium from a Dalhousie sediment containing 6.7 ppm of cadmium and no bioaccumulation of cadmium from a Dalhousie sediment containing 2.2 ppm of cadmium.

The pattern for M. arenaria was virtually the same with an equilibrium level of around 0.6 µg/g after 30 days and maintained until the end of the experiment.

None of the other seven organisms accumulated any cadmium in their tissue, even from the highly contaminated Belledune sediment. Even Nereis sp., which feeds on sediment and was observed to have sediment in the gut tract when removed from mud, showed only trace amounts of cadmium in tissue.

The cadmium in Dalhousie West Bay sediment is probably bound to the sediment in such a way as to be unavailable for bioaccumulation. Even the very highly contaminated Belledune sediment would appear to have a large portion of the cadmium in biologically unavailable forms.

The fact that total metal concentration in sediment may not be the appropriate measurement when looking into bioaccumulation is not new (Loring, 1981; Ray et al., 1981). The actual extraction method used to determine that portion of the cadmium that might be available to marine animals has been debated and several researchers have proposed methods for such determinations.

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2.6 DREDGING OF THE HARBOUR OF DALHOUSIE, N.B. 1970-1980: AN OVERVIEW

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Historical Background

Dalhousie is a small commercial port located in northwestern New Brunswick, where the Restigouche River enters the Bay of Chaleur (Figure 2.11). The port has two major port-oriented industries: New Brunswick International Paper (pulp and paper facility) and Brunswick Mining and Smelting Corp (a lead/zinc ore loading facility) (Figure 2.12). As well, the City acts as a port for that section of New Brunswick.

Dredging has been undertaken at the port for many years (Table 2.4 gives quantities dredged 1950-1974), both during capital construction of wharves and for maintenance of docking access. Until 1972 the dredged material was disposed at a number of locations. In that year the Environmental Protection Service (EPS) required Public Works Canada (PWC), the dredging proponent, to dispose of the material at an open-water site near Heron Island in the western basin of the Bay of Chaleur. This site was used from 1972 to 1978 with approximately 280,000 m^3 of material being deposited. At that time, the concern was of sediment concentrations of mercury attributed to a chlor-alkali plant upriver of the West (or Public) Wharf dredge site. Table 2.5 lists the source and frequency of dredged spoil disposed at the Heron Island Ocean Disposal Site.

In 1975 Canada passed the Ocean Dumping Control Act, which served to place restrictions on the composition of material that could be disposed in the sea. This law was designed to include the open-water disposal of dredged materials and included a maximum allowable limit for cadmium of 0.60 mg/kg. As can be seen in Table 2.6, the dredged sediments from the harbour were found to contain cadmium in excess of this limit. Thus, EPS

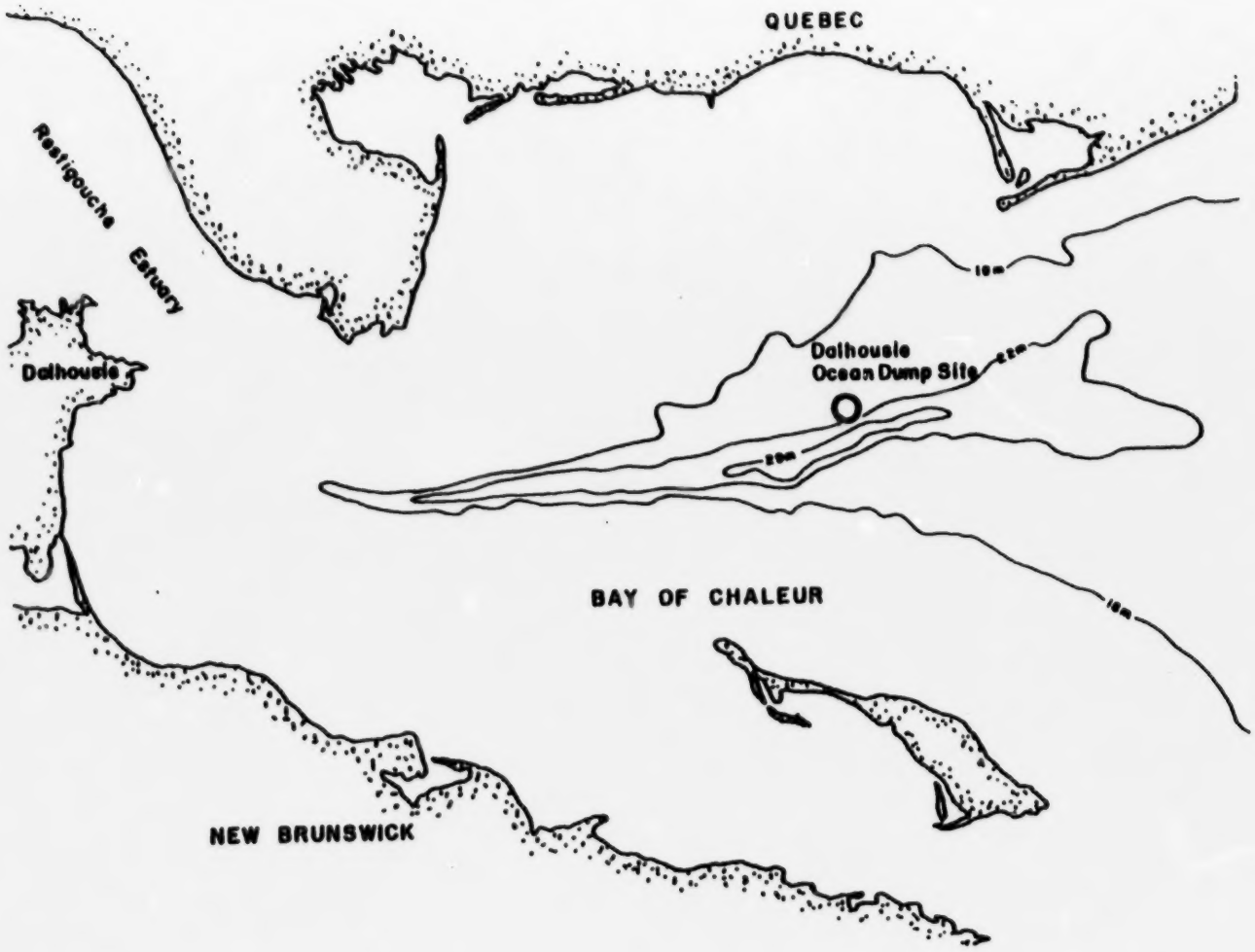

Figure 2.11

Dalhousie, New Brunswick and dump site study area.

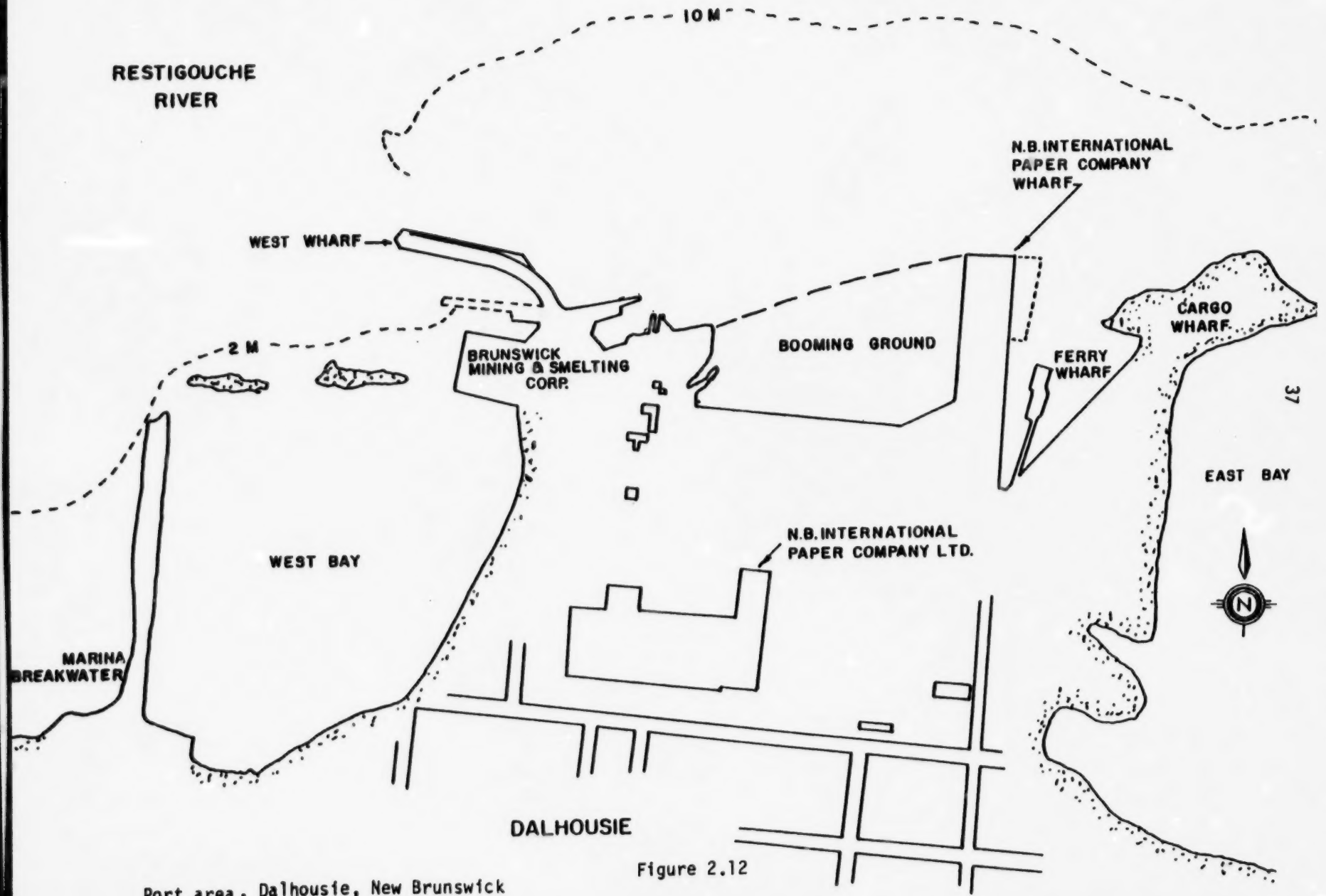

Figure 2.12

Port area, Dalhousie, New Brunswick

Table 2.4

Dredged Quantities from Dalhousie, New Brunswick
(McLean and MacGregor, 1976)

Year		Quantity (cypm *)	Remarks
1950		26,710	Contract, deep water wharf.
1951		Nil	
1952		1,853	Contract, paper company wharf.
1963		10,446	Contract, paper company wharf.
1954		18,401	Contract, paper company wharf.
1955		27,110	Contract, paper company wharf.
1956		688	Contract, ferry wharf.
1957		11,994	Contract, paper company wharf.
1958		Not recorded	Contract, deep water wharf, → 28'.
1959		22,126	Contract, deep water wharf.
1960		13,958	Contract, paper company wharf.
1961		Nil	
1962		7,942 13,606	Contract, paper company wharf. Contract, public wharf.
1963		268,720	Contract, lengthening berth, public wharf, → 34'
1964		19,064	Contract, public wharf.
1965		18,227	Contract, public wharf, berth and approaches.
1966		32,800	Contract, public wharf, berth and approaches.
1967		31,915	Contract, public wharf, berth and approaches.
1968		23,622	Contract, public wharf, berth and approaches.
1969		46,021	Contract, public wharf, berth and approaches.
1970		20,410	Contract, public wharf, berth and approaes.
1971		29,850	Contract, public wharf → 34', sand and gravel, disposal 3 1/2 miles.
1972			
1973	Aug.-Oct.	20,902	Contract, cargo wharf, disposal 3 miles.
	Aug.-Oct.	438,936	Contract, cargo wharf, disposal 10 miles, disposal 48° 03' 00" N, 66° 10' 00" W.
	May-June June-July	9,100 37,657	Contract, ferry terminal, class B. Contract, wharf, class B.
1974	Aug.-Sept.	56,206	Contract, wharf, class B. Disposal 48° 03'00" N, 66°10'00" W in 60 feet water.

* Cubic Yards Place Measure

Table 2.5
Source and Frequency of Dredge Spoil
Dumping at the Dalhousie Ocean Dump Site
(W. Lord, Public Works Canada, pers. comm.)

SOURCE	YEAR	AMOUNT (m^3)
Dalhousie West Wharf	1973	35,991
Dalhousie Ferry Wharf	1973	173
Dalhousie Cargo Wharf	1973	19,956
Dalhousie West Wharf	1974	53,720
Dalhousie Cargo Wharf	1977	57,487
Dalhousie Cargo Wharf	1978	65,941
Totals	5 (Years)	280,021

Table 2.6
Ocean Dumping Permit Analyses
(P. Eaton, EPS, pers. comm.)
(mg/kg)

	Zn	Cd	Hg	
West Wharf	982	2.7	0.3	
Cargo Wharf	389	1.6	0.3	
Main Channel (near West Wharf)	135	1.37	0.58	
Cargo Wharf	42	0.36	0.47	(Cu = 7) (Pb = 19)

(The cargo wharf sediment was the most recent material taken to the ocean dump site.)

refused to issue an Ocean Disposal Permit for this site after 1978 and suggested that PWC place dredged spoils in a small bay at the western end of the port. The location was chosen because the sediment type and trace metal contamination were similar to those of the proposed dredging areas near the West and Cargo Wharves.

This unconfined intertidal site was used in 1979 and 1980. However, by autumn 1980 the embayment was essentially filled and large spoil mounds can be observed even at high tide. At low tide the bay is essentially a mud flat (Figure 2.13).

A problem that has arisen with the use of West Bay as a dredged material disposal site is that the use interferes with the docking and mooring facilities of the Dalhousie Yacht Club. The Club has requested that if PWC continues to use West Bay, then a new club facility should be provided.

A deadlock appears to have developed. Although the port has spent a considerable amount of money on a port design, the topic of dredged material disposal has not been taken into account. With EPS refusing to permit ocean disposal at the Heron Island dump site and with the use of West Bay, a socially, and possibly environmentally, unacceptable alternative, the dredging proponent and the port are now faced with the problem of of how to dispose of the dredged material in an environmentally, socially, and economically acceptable fashion.

Scientific Evaluation

Recognizing the potential deadlock developing, Brunswick Mining and Smelting contracted MacLaren Plansearch (November 1979; June 1980) to conduct an extensive study of the harbour and environs (Figure 2.14) with the objectives of assessing:

(a) the distribution of sediment cadmium in the study area,

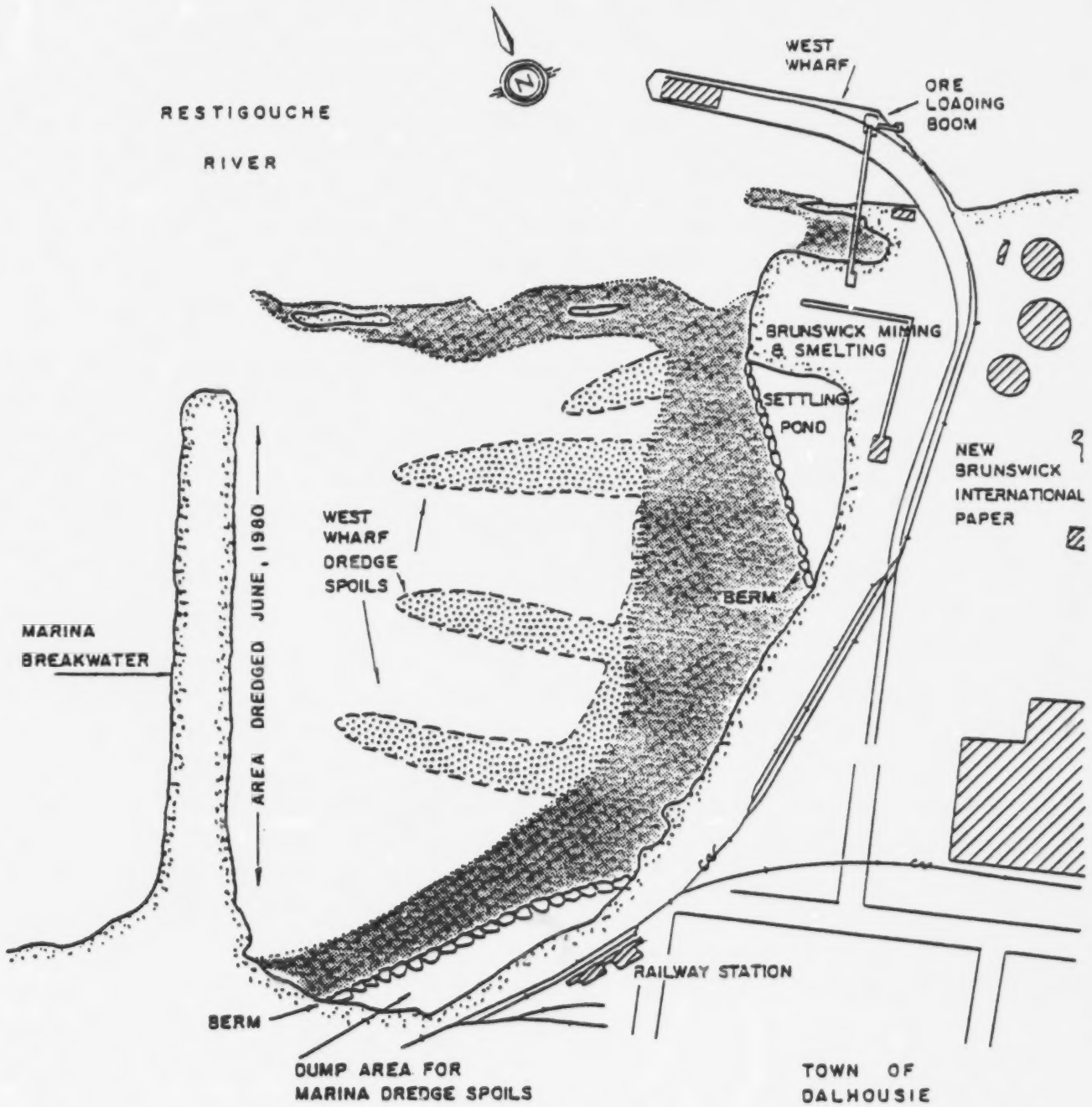

Figure 2.13

Disposal area West Bay, Dalhousie, New Brunswick

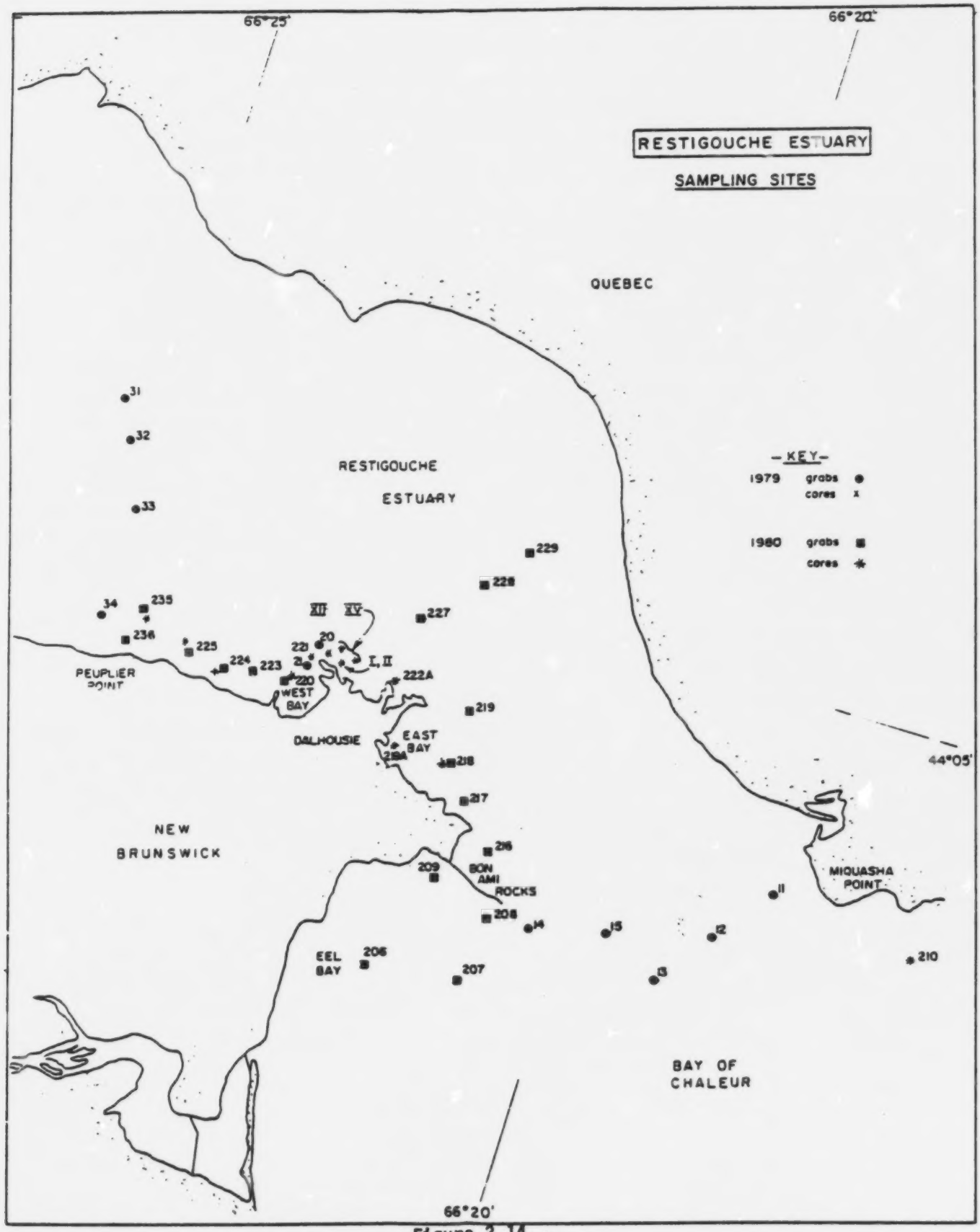

Figure 2.14
Sediment sampling sites, Restigouche estuary.

(b) the relationship of sedimentary physico-chemical environment to the cadmium distribution, and

(c) the relationship between cadmium benthic body burdens and sediment concentrations;

with the overall objective being to assess the bioavailability of sediment cadmium in the proposed dredge areas to the local benthos.

Concurrently, MacLaren Plansearch was funded by RODAC-Atlantic to complete analyses of samples collected by the Atlantic Geoscience Centre in September 1978 and September 1980 at the Heron Island disposal site (Figures 2.15 and 2.16). The objective of these programs was to determine the changes in trace metal distribution and possible benthic bioaccumulation since the cessation of disposal in 1978.

The findings of the harbour/estuary studies are as follows:

- Both the NBIP and BMS are significant contributors to harbour sediment pollution: NBIP with log/wood wastes adding to the siltation problem; BMS contributing trace metals, especially cadmium (an ore impurity).

- Concentrations of sediment cadmium in the proposed dredging area adjacent to West Wharf are in the 6 to 10 mg/kg range extending 200 cm into the sediment.

- There is a decrease in concentrations proceeding into the estuary away from the wharf area.

- There is a significant correlation of total cadmium distribution in estuarine sediment with sediment organic carbon and silt-sized sediment distributions.

- The cadmium body burdens of benthic fauna collected in the study area were generally low and cannot be correlated with total cadmium concentrations in the sediments.

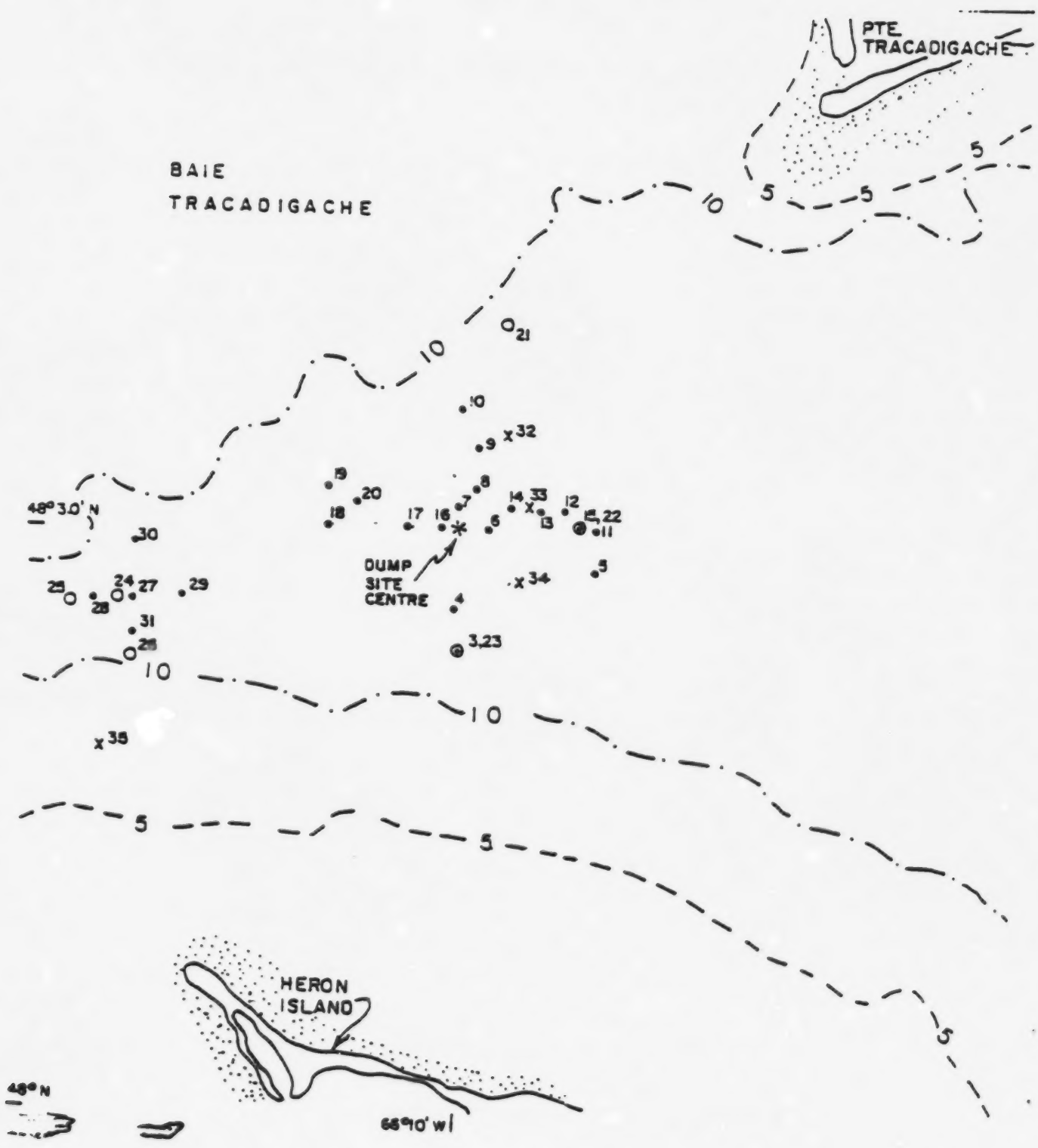

Figure 2.15
Sediment samples at Heron Island dump site, September 1978.

Sediment sampling sites, Restigouche estuary.

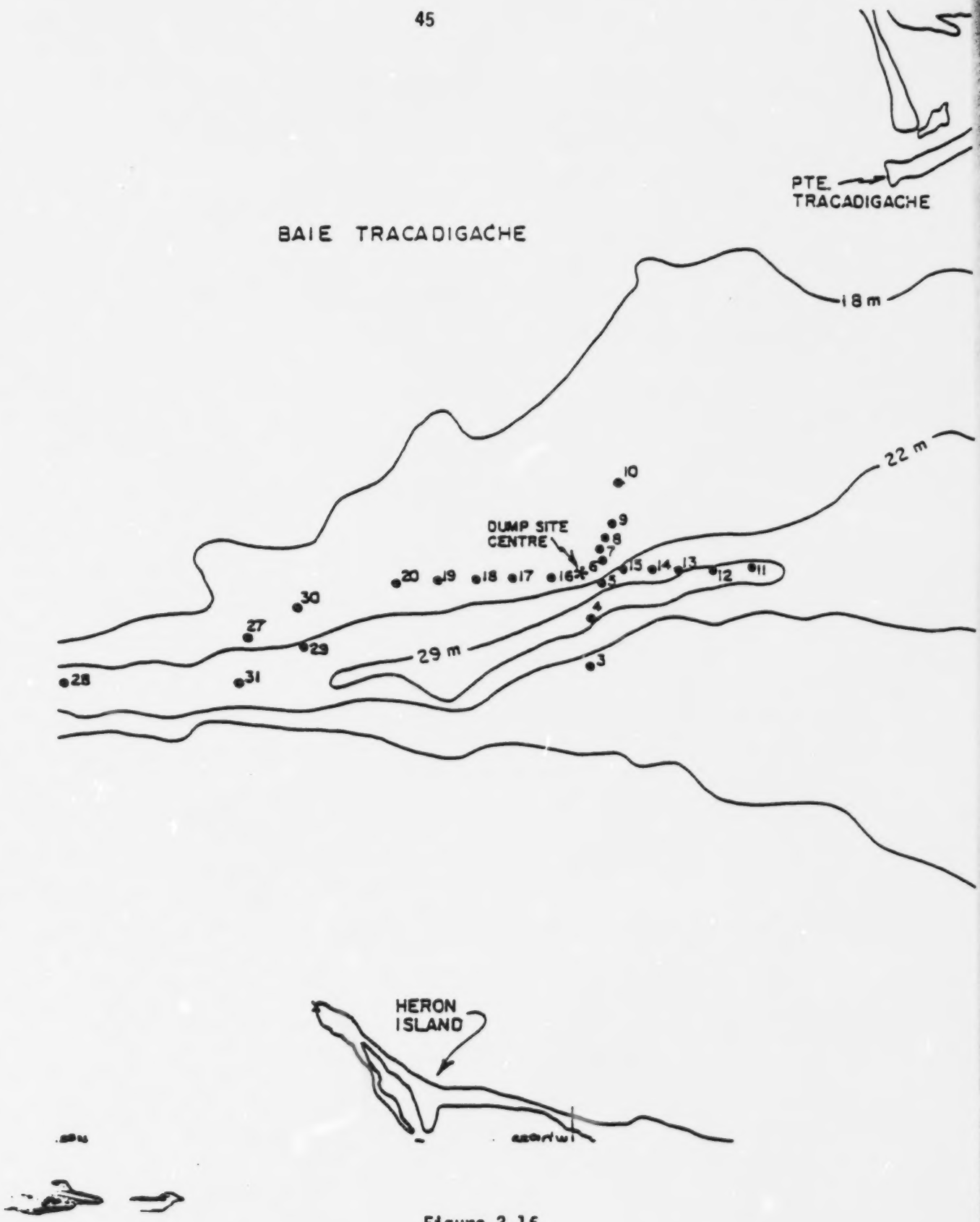

Figure 2.16

Sediment samples at Heron Island dump site, September 1980.

- Macoma balthica, exposed in laboratory bioaccumulation tests to sediments from five areas of the harbour, did not show statistically significant uptake of cadmium. This agreed with the laboratory results of Ray et al. (1981).

Thus we concluded that the cadmium in the harbour sediments was not bioavailable. Also, as some ore or surficial runoff was still entering the sediment system, the cadmium from that source rapidly immmobilized and was retained in the sediment.

The findings of the 1978 open-water disposal site survey are as follows:

- The dump spoil could not be distinguished by geophysical means from the surrounding sediment.

- Using lignin (wood fibre) as a geochemical tracer, the site could be clearly distinguished from surrounding sediment. The dredge spoil composition and the geochemical distributon of metals in the sediment were very similar to those in Dalhousie Harbour sediments, from whence the dredged materials came.

- The zinc and cadmium were primarily associated with the hydrogen peroxide leach fraction of the sediment.

The findings of the 1980 survey are somewhat different:

- Concentration of surficial total cadmium and zinc were less in 1980 than in 1978.

- Most of the benthic biota collected from the site did not show uptake of cadmium; the exception was scallops.

- Using lignin (wood fibre) as a tracer, the dredge spoil site was still discernible, but much less so than in 1978.

The differences between the 1978 and 1980 surveys probably reflect a combination of three possible processes:

1. diagenesis in the sediment leading to alteration of the geochemical distribution of metals;

2. natural sedimentation 'covering' the dredge spoils; and

3. 'winnowing' of sediment from the site due to bottom currents or storms.

Conclusion

RODAC-Atlantic has expressed concern for the concentrations of cadmium in the harbour sediments and has therefore vetoed the use of an open water disposal site citing the potential for contamination of biota by the trace metals in the dredge spoils. On the basis of the scientific studies conducted, the cadmium has been shown to be nonbioavailable. Provided that the sediment at the disposal site remains essentially undisturbed, the cadmium should remain chemically immobilized. The more general concern that physical processes at the open-water site may lead to sediment redistribution (and therefore contaminant transport) is an acknowledged, but unknown, parameter. Therefore, I recommend that, before large amounts of money are spent on an upland or shoreline containment facility, because open-water disposal is not permitted, an in-depth evaluation of the economic and environmental consequences of all three disposal alternatives be conducted.

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2.7 FORAMINIFERAL COLONIZATION OF AN OFFSHORE DUMP SITE IN CHALEUR BAY, NEW BRUNSWICK

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Abstract

Living benthonic foraminifera populations were surveyed at the Chaleur Bay ocean disposal site one month after the cessation of dumping activity in September 1978, and again two years after in September 1980.

After one month the pioneer species Eggerella advena and Ammotium cassis had repopulated most of the dump site substrate. All localities were repopulated by 1980 and the proportion of E. advena showed an increase relative to A. cassis. The total number of living species observed increased from 13 in 1978 to 37 in 1980. The average population density in terms of the number of living specimens per cubic centimetre of wet sediment increased from 3.1 in 1978 to 27.1 in 1980.

Introduction

The disposal of solid waste in the marine environment at sites off the east coast of Canada has usually been confined to dredge spoil which sometimes contained a high concentration of organic matter. This organic material was derived primarily from municipal waste systems or from local paper mills. It was often deliberately or inadvertently introduced into the nearshore zone through various types of intertidal or subtidal outfalls, or as the result of landfill operations (e.g. Schafer and Cole, 1974). Resuspension and deposition of this material along with indigeneous sediments to navigation channels and dockside areas results in the accumulation of mixed sediment deposits that must be removed on a fairly regular basis through a program of maintenance dredging. One dump site used for dredge spoil disposal is located in a lower estuarine environment in the western part of Chaleur Bay (Figure 2.17). It was used fairly regularly for a six-year period and ranked second on the east coast in terms of total

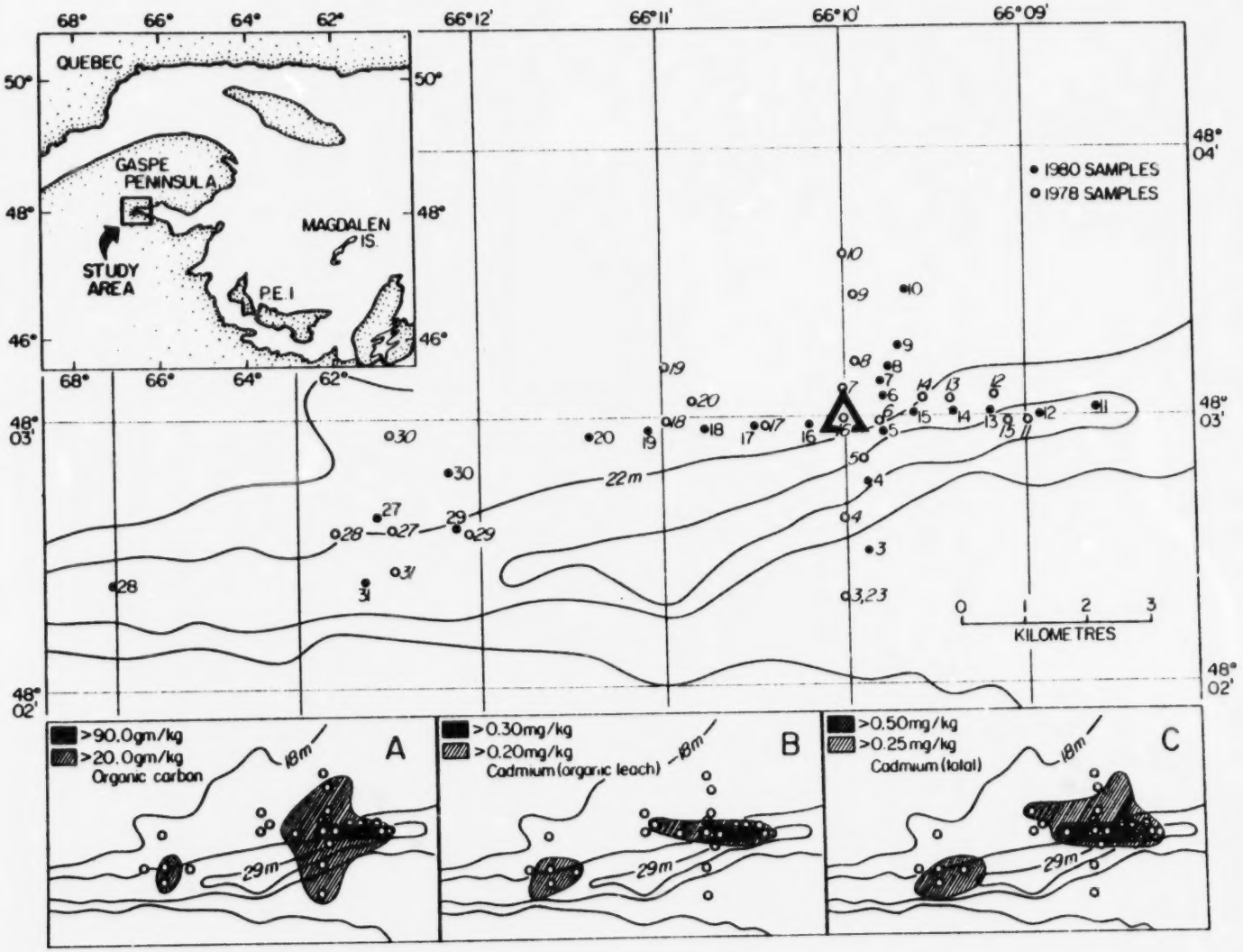

Figure 2.17

Dump site location Chaleur Bay

volume of dredge spoil deposited (280,000 m^3). Since 1978 the site has not been used and spoil from the Dalhousie area has been dumped elsewhere because of its high cadmium content (i.e. greater than 0.6 mg/kg). The dumping of sediment dredged from wharf areas at Dalhousie, New Brunswick, was initiated at the site in 1973 (Table 2.7). On the average about 45,000 m^3 of spoil per year was dumped between 1973 and 1978. For an assumed dumping radius of 1 km from the dump site marker, and for even redistribution of sediment, spoil deposition would have averaged about 5 cm/yr or about 28 cm over the period that the site was used.

This report summarizes the nature of the living foraminifera population at the dump site in September of 1978 (just one month after the last dumping occurred) compared to the population that was observed at the site during the same month in 1980.

Dump Site Conditions

The 1978 geochemical survey of bottom sediments at the dump site (McKnight and Schafer, 1980) indicated that the overall distribution of dredge spoil could be mapped using trace metal concentration data. Total cadmium concentrations were highest near the location of the dump site centre marker buoy and decreased away from this position, eventually reaching ambient concentrations of 0.2 to 0.4 mg/kg at an average radial distance of about 1.1 km (Figure 2.17C). For the organically-leached cadmium in the sediment (Figure 2.17B), there appeared to be a distinctive east-west trend of relatively high concentrations that could be related to resuspension and transport of fines by tidal currents. Suspended particulate matter (SPM) that was collected one metre above the bottom at the dump site in 1978 showed a significant enrichment in cadmium compared to control samples collected at Stations 27 and 28 to the west of the dump (see Figure 2.17), suggesting possible transport of resuspended spoil throughout a larger area of the bay.

Wood chips and associated organic pulp-mill waste dredged from the channel and harbour areas around Dalhousie are colonized by marine bacteria that promote the development of reducing conditions at relatively

Table 2.7

Source and Frequency of Dredge Spoil Dumping at the Western Chaleur Bay Site. Dredging operations were usually carried out between July and October (W. Lord, pers. comm.).

SOURCE	YEAR	AMOUNT (m^3)
Dalhousie Public Wharf	1973	35,991
Dalhousie Ferry Wharf	1973	173
Dalhousie Cargo Wharf	1973	19,956
Dalhousie Public Wharf	1974	53,720
Dalhousie Public Wharf	1975	46,767
Dalhousie Cargo Wharf	1977	57,487
Dalhousie Cargo Wharf	1978	65,941
TOTALS	5 (Years)	280,021

shallow (0 to 4 cm) sediment depths near the dump site centre. The distribution pattern of this woody material follows the pattern of sedimentary organic carbon (Figure 2.17A), i.e., a general west-to-east trend of relatively high concentration that is comparable to the total cadmium pattern. The diver observations and the geochemical results indicate significant, although not complete, redistribution of spoil beyond the immediate vicinity of the dump site.

With the exception of several barren stations near the dump site centre, the range of living species diversity in 1978 was comparable at the dump site and at the control site. Buccella frigida, Miliammina fusca, Reophax arctica, and Elphidium bartletti were observed only at the dump site (mostly to the north of the dump site centre) where Hemisphaerammina bradyi, Saccammina atlantica, and Cribrostomoides carssimargo were confined to the control site. Although the occurrence of all of these species is comparatively widespread throughout the bay, their distribution pattern is heterogeneous and they often represent less than 2% of the living population.

All of the September 1980 samples contained relatively large numbers of specimens compared to the 1978 material. Population densities at the dump site in 1980 averaged 27.5 NL (Number of living specimens)/cc and 25.4 NL/cc at the control site versus 2.6 NL/cc and 4.7 NL/cc, respectively, for the same areas in 1978. The number of living species also showed an increasing trend over the two-year period; 1978 dump-site and control-site averages were 3.4 and 3.6, respectively, versus 9.9 and 8.4 in 1980. The grand average number of species at the dump site in 1980 was somewhat higher than observed at the control site, indicating that perhaps a transitional zone capable of supporting a relatively complex living assemblage had developed on the periphery of the dump site centre over the two-year period. This condition is also suggested by averages of living species taken over 1 km radial distances from the dump site centre (Figure 2.18). Favorable ambient conditions in this peripheral zone might allow the indigenous benthos to utilize the organic matter component of redeposited dredge spoil (e.g., Bellan and Bellan Santini, 1970; Rhoads et al., 1978; DeLaca et al., 1981). However, most of the living foraminifera

that give rise to the relatively high species diversity relationship in the 1980 samples are rare forms (5%) and cannot be used independently to test the enhanced peripheral environment hypothesis. The probable existence of this local environment in 1980 is suggested by the comparatively high NL/cc values that occur at Stations 9, 12, and 13, which lie to the north and east of the dump site centre. Conversely, mean compound diversity results considered as a function of radial distance (Figure 2.18) indicate a major change in the structure of the living foraminifera population that is most pronounced wthin a 1 km radius of the dump-site centre.

The relatively high mobility of E. advena and of Elphidium excavatum group may explain the increased proportion of these species at the dump site during 1980. Conversely, the reduction in Ammotium cassis percentages since 1978 suggests reduced concentrations of suspended particulate matter (SPM) following the cessation of dumping activities. This condition could be enhanced by a gradual stabilization of the bottom sediment as a consequence of recolonization, and of ongoing physical reworking processes that promote the resuspension and removal of fines to adjacent deeper and/or sheltered environments.

Summary

Disposal of dredge spoil at the Chaleur Bay ocean dump site can be characterized by the distribution of trace metals such as cadmium. Their pattern suggests an east-to-west redistribution of the spoil which may have resulted from several factors including the initial dumping pattern, redistribution of biologically resuspended sediment by tidal currents, and/or redistribution during storm events.

In 1978, about one month after the last dumping activity, foraminifera had repopulated most of the spoil substrate with the exception of two stations adjacent to the dump site centre marker buoy. The pioneer species consisted primarily of Eggerella advena and Ammotium cassis. By 1980 all localities at the site were inhabited by foraminifera and the pro-

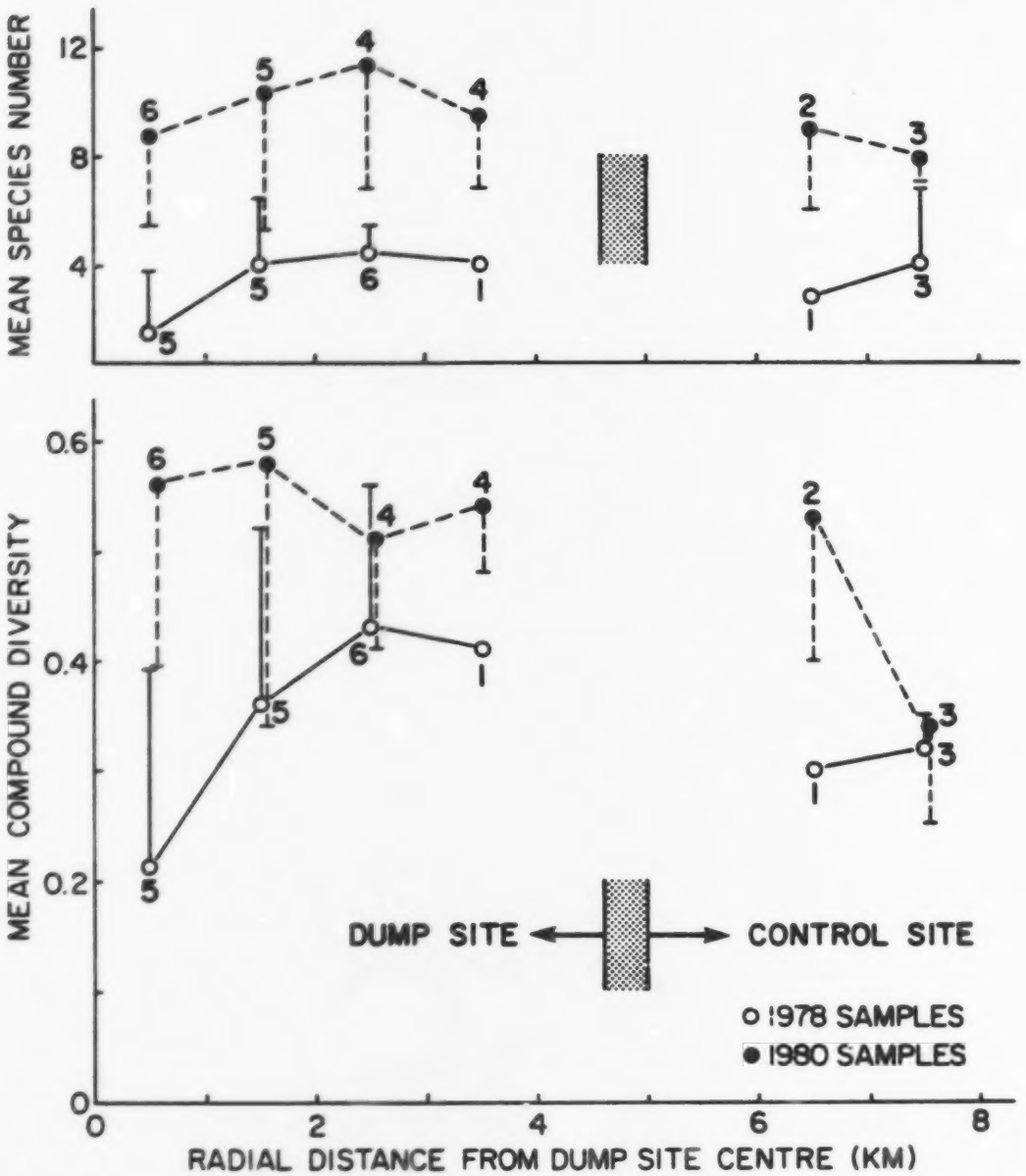

Figure 2.18

Compound diversity and species number with radial distance from dump site.

portion of Eggerella advena had increased at the expense of Ammotium cassis. This change may be related to a stabilization of the sediment substrate as a consequence of physical and biological reworking with a consequent reduction in ambient SPM concentrations. Additional species observed at the site in 1980 support the contention that the foraminifera are repopulating the reworked oxidized sediment that has been deposited over the spoil at most localities near the dump site centre.

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2.8 THE ATLANTIC REGIONAL LABORATORY EVALUATION PROGRAM SECOND QUALITY CONTROL ROUND ROBIN

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Abstract

The Atlantic Regional Laboratory Evaluation Committee has conducted quality round robins and organized a workshop in the Atlantic Region with special emphasis on cadmium measurements in sediments. The majority of the participants were not able to measure cadmium within acceptable precision and accuracy. It is recommended that the laboratories in the region be encouraged to participate in quality control round robins and emphasis be placed on effective information dissemination through workshops, seminars, and training.

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* Presented on behalf of the Laboratory Evaluation Committee, consisting of:

Dr. Hari S. Samant, Chairman
Dr. Doug Loring, AOL, Bedford Institute of Oceanography, Dartmouth, N.S.
Dr. Shankar Ray, Biological Station, Fisheries Management, St. Andrews, N.B.
Dr. Tom Pollock, Water Quality Branch, Environmental Conservation Service, Moncton, N.B.
Dr. Dave Jamieson, National Research Council, Halifax Laboratory, Halifax, N.S.

Introduction

Quality control is important in any product line. However, it becomes absolutely essential in multidisciplinary projects where various activity components and measurements are carried out by scientists of differing disciplines and background, and far-reaching decisions are made on such measurements. Within the past few years concern has been growing regarding the quality of environmental data. For example, the National Academy of Sciences, in a study done for the U.S. Environmental Protection Agency, concluded that "inadequate use of scientific principles" in monitoring programs was producing "data of poor or unknown quality." In a recent paper, Hunter (1980) stated that "many measurements, both those in everyday use and those arising from sophisticated laboratory investigations, should be viewed with skepticism."

As difficult as they are, quality control checks are easier to apply to laboratory measurements than those related to field work, e.g., equipment and methodology, site selection, sample collection and handling, and the like. In order to provide reliable environmental data, quality control checks must also be applied to field work. Reed (1981) has outlined a simple, integrated, self-explanatory quality assurance program which is reproduced in Figure 2.19. The program emphasizes a good planning, clear understanding of the objectives, selection of methods, and quality control measures among other aspects of a project. The need for better liaison and coordination of various aspects of a project are further emphasized by Hamilton (1981).

The current Laboratory Evaluation Program applies only to laboratory measurements, and more precisely, to chemical analyses. Previous work related to this program included a quality control round robin (Samant et al., 1979) and a quality control workshop (ARL, 1981).

Presented here is a report on the second quality control round robin under the auspices of this program.

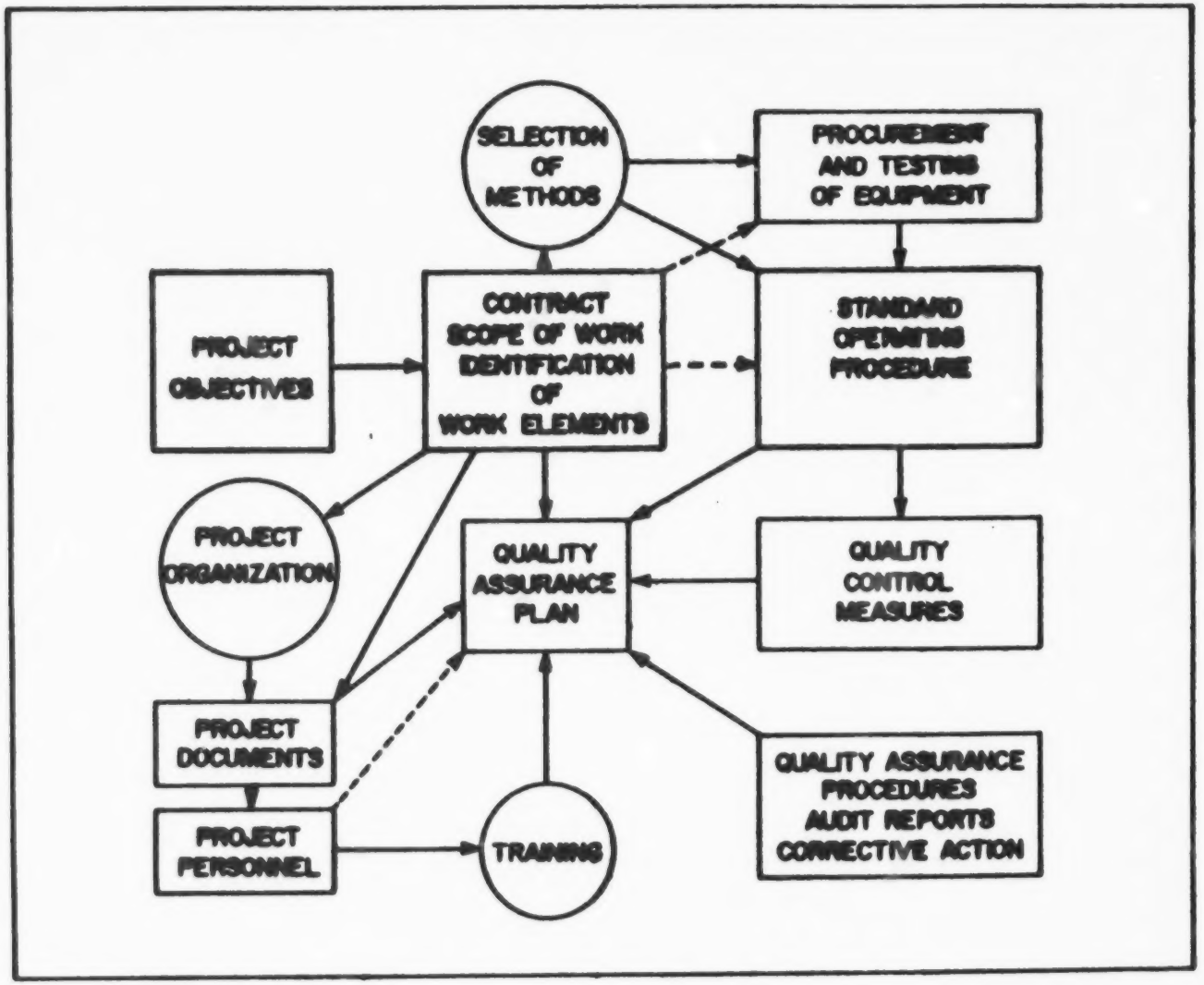


Figure 2.19

General outline of a quality assurance program.

The unknown samples for the second round robin were sent out June 21, 1980. They consisted of two reference materials, MAG-1 and WQB-2.

The USGS Marine Mud, MAG-1, was used in 13 replicates of Bottles 1 and 3 while WQB-2 was placed in 13 replicates of Bottles 2 and 4. The characteristics of MAG-1 are contained in the Technical Report (Samant et al., 1979) of the first round robin.

The Inland Waters Directorate Sample WQB-2, weighed from a single bottle, is a sample of mid-Lake Ontario sediment ground to 200 mesh and freeze-dried (Aspila, 1979).

The elements to be measured in these standards were:

- cadmium
- copper
- lead
- zinc

Results and Discussion

The laboratory results for MAG-1 and WQB-2 are presented in Tables 2.8 and 2.9, together with the analytical and instrumental methodology.

Figures 2.20 and 2.21 show the range of values for the various laboratories on the duplicate samples of MAG-1. For lead, the majority of values are close to the 1:1 line indicating that between-run precision is high. Laboratories #2 and #4 have poor between-run precision. Using the "± 50% of the recommended value" which was accepted for the first round robin, Laboratories #5 and #4 generated unacceptable results, as did Laboratory #2 half of the time. There is no obvious bias in the results for lead from laboratories which did not destroy the silicate matrix with hydrofluoric acid.

Table 2.8
Comparative laboratory analytical results for sediment MAG-1

mg/Kg

LAB #	Cd		Cu		Pb		Zn		Digestion	Instrumentation
	1	3	1	3	1	3	1	3		
1	0.25, 0.30		29.4	30.1	27.4	32.7	135	138	HCl, HNO_3, HF	AA
2			10	20			103, 131	100, 129	$HNO_3, HClO_4, HF$	GFAA*
3	0.25, 0.30	0.25, 0.25	8.3, 25 25, 26	26.5, 24 24, 24	10, 10 28, 29	42.3, 36 26, 30	111, 107	122, 128	HNO_3, HCl	AA dir AA ext AA GFAA
4			30	20	50	40	110	110	HNO_3, HCl, HF	AA
5	L5	L5	41	39			106	105	HNO_3, HCl	AA
6			28	28	12 26	14 25	131	130	$HNO_3, HClO_4, HF$	GFAA ICAP**
7	0.17 0.7	0.17 0.7	28 24	24 24	25 30	25 30	117	120	HNO_3, HCl	GFAA AA
$\bar{x}$	0.33 ± 0.20		25.4 ± 7.3		27.4 ± 10.4		118.5 ± 12.3			
Median	0.25		25.5		27		118.5			
Literature	0.2		30		27		135			

* GFAA: graphite furnace atomic absorption

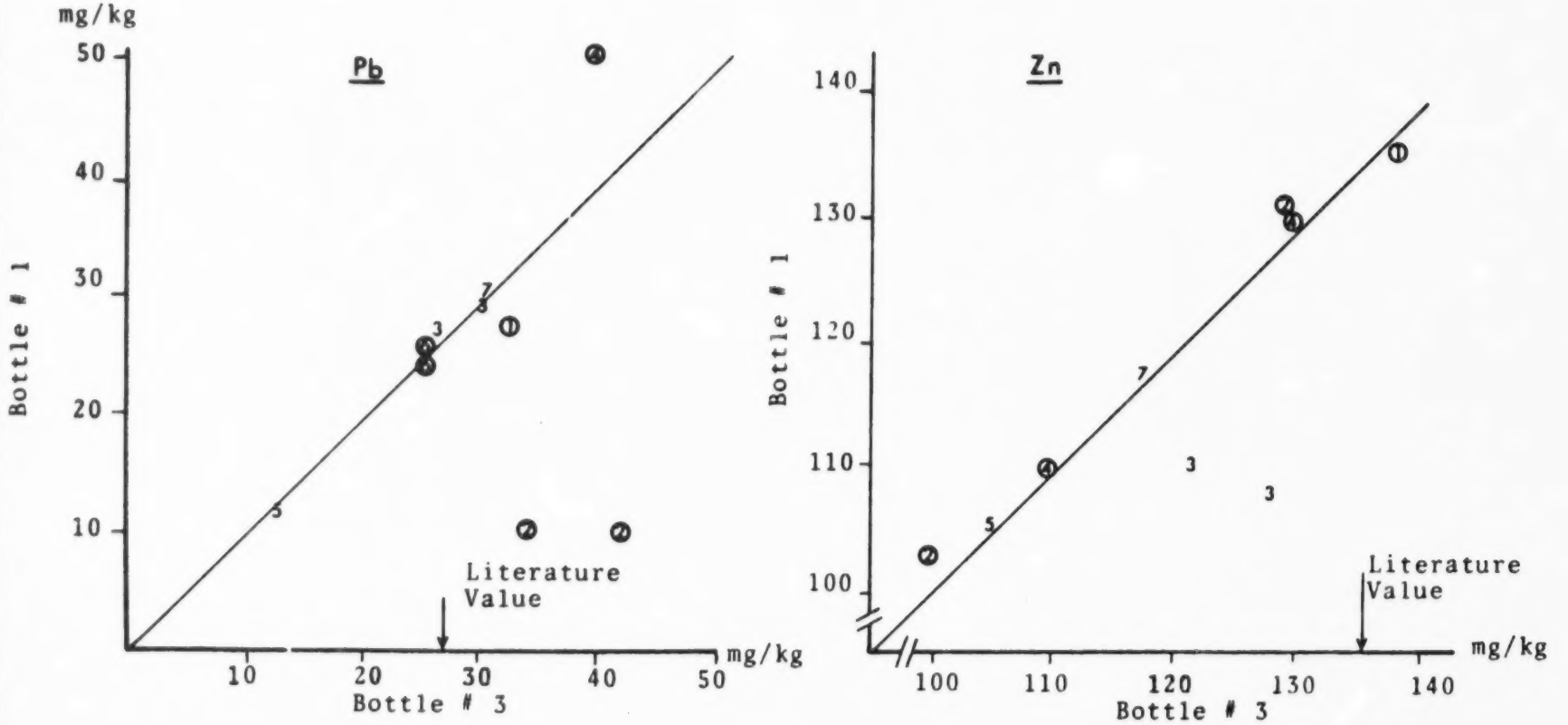
** ICAP: inductively coupled argon plasma

Table 2.9 - Comparative laboratory analytical results for sediment MAG-2 WQB-2

mg/Kg

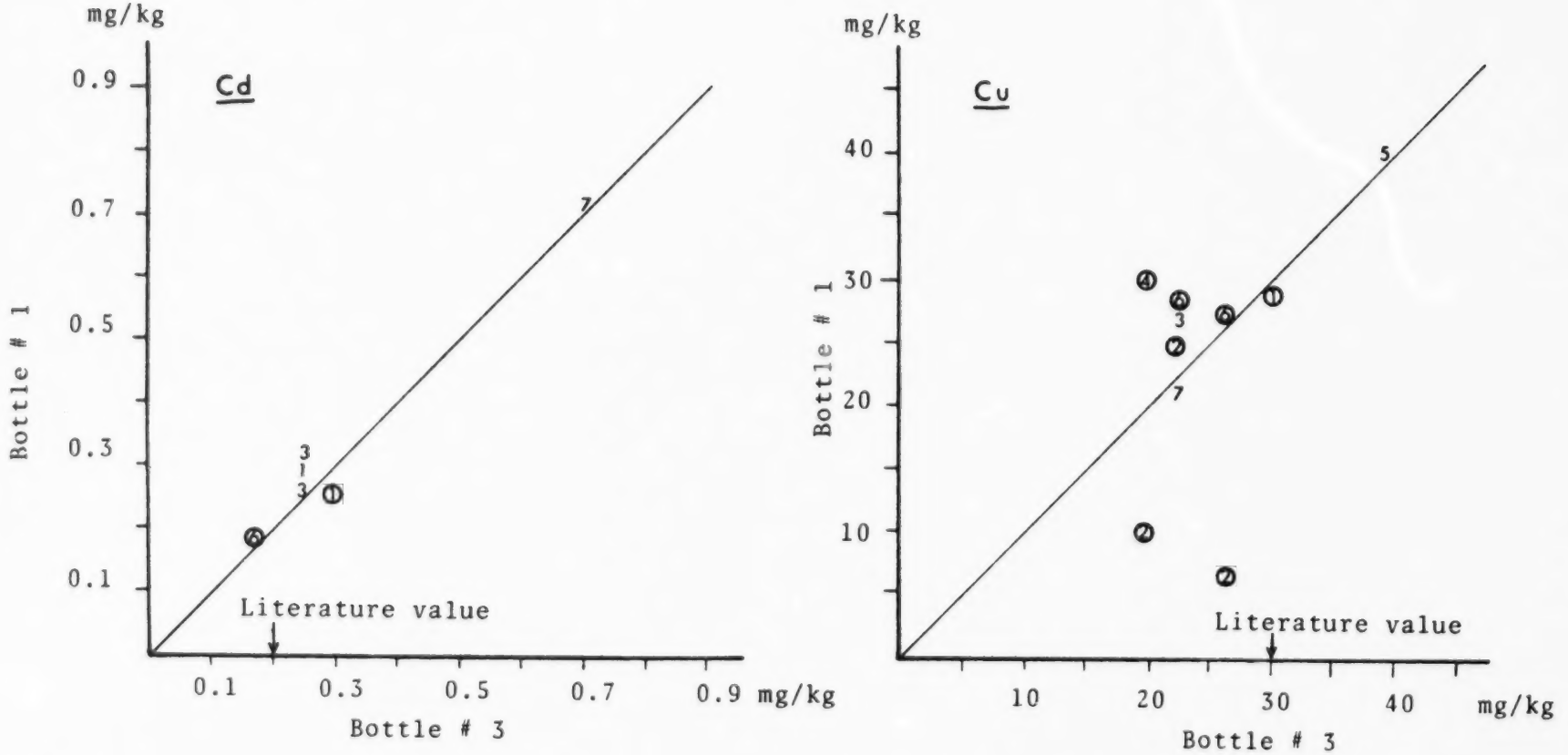
LAB #	Cd		Cu		Pb		Zn		Digestion	Instrumentation
	1	3	1	3	1	3	1	3		
1			86.4	81.2			278	265	HCl, HNO_3	AA
	2.9*	4.25			57.5	74.2				GFAA*
2			50.5, 71.5	99, 60			222, 235	249, 251	HNO_3,$HClO_4$,HF	AA dir
			59, 85	69.7, 57.5	49.3, 68.7	105, 79.2				AA ext
3			72, 71	72, 71	80, 80	80, 80	238, 240	260, 245	HNO_3, HCl	AA
	1.4, 1.1	1.3, 1.0								GFAA
4			90	90	110	100	260	260	HCl,HNO_3,HF	AA
5			83	86			243	234	HNO_3,HCl	AA
	L5	L5			14	13				GFAA
6			77	78	76	73	268	267	HNO_3,$HClO_4$,HF	ICAP**
	1.3	1.6	68	74	77	80				GFAA
7	2.0	2.0	76	75	95	92	257	254	HNO_3,HCl	AA
$\bar{x}$	1.89 ± 1.01		74.7 ± 11.1		74.2 ± 25.3		251 ± 14			
Median	1.5		74.5		79.6		252.5			
Literature	1.8		78.6		83.8		276			

* GFAA: graphite furnace atomic absorption
** ICAP: inductively coupled argon plasma



Laboratory results for MAG-1. Bottle # 1 vs Bottle # 3. Circled number indicates laboratories using HF digestion.

Figure 2.20



Laboratory results for MAG-1. Bottle # 1 vs Bottle # 3. Circled number indicates a laboratory using HF digestion.

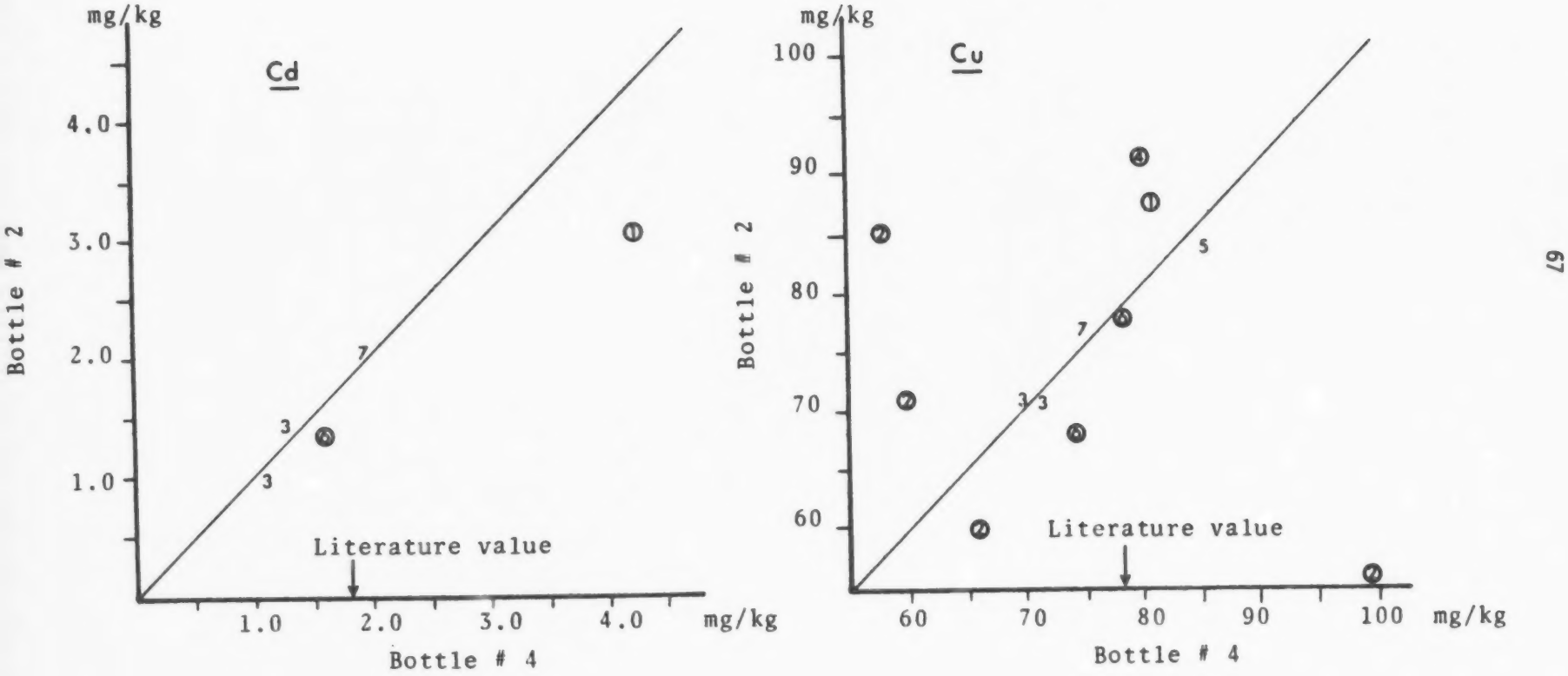
Figure 2.21

The graph for zinc indicates that only Laboratory #3 was having any difficulty with between-run precision as determined by analysis of duplicates. All of the laboratories produced data acceptable for the criterion of "literature value ± 25%." Again, there is no discernible difference in results from analyses which used a hydrofluoric acid digestion step and those which did not use this method.

In Figure 2.21 the graph for cadmium illustrates again that the level of cadmium in MAG-1 presents problems for many laboratories. Only four of the seven reporting laboratories included cadmium results. Three of these were within the very lax criterion of ±50% of the recommended values. Laboratory #7 reported the cadmium results in excess of the literature value by a factor greater than three. Again, the results suggest that there is no residual cadmium being retained in the crystal lattice of the sample.

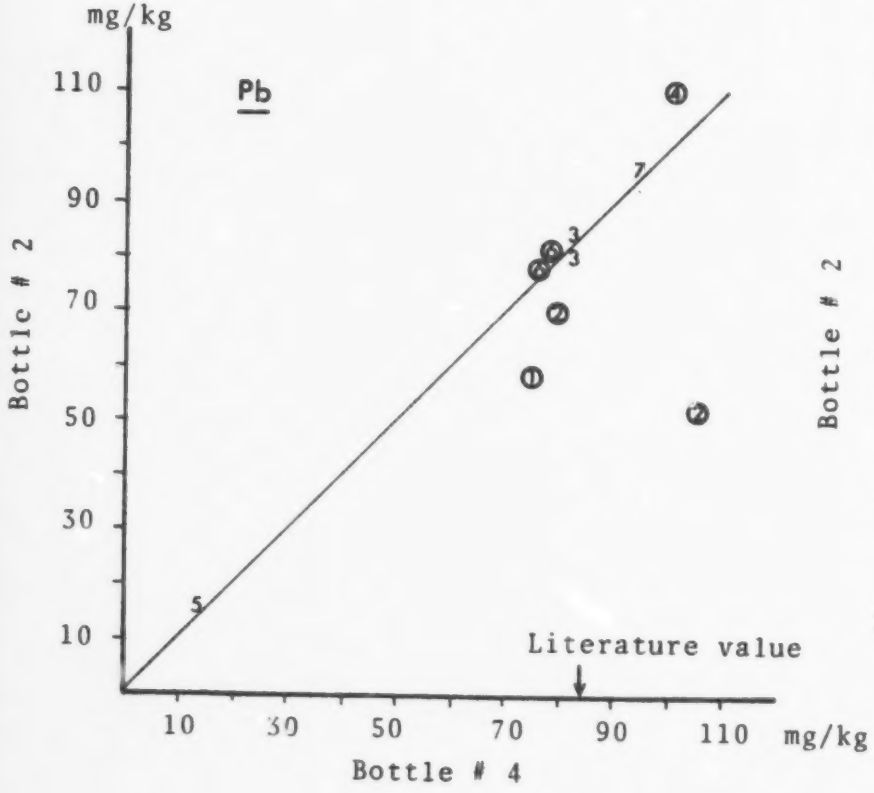
The results for copper look reasonably precise with the exception of those from Laboratory #4 and two of the three from Laboratory #2. As was the case for zinc, the median value for the copper data is significantly below the value recommended in the literature, though all but two of the results are well within the ±50% spread which was deemed acceptable in the first study.

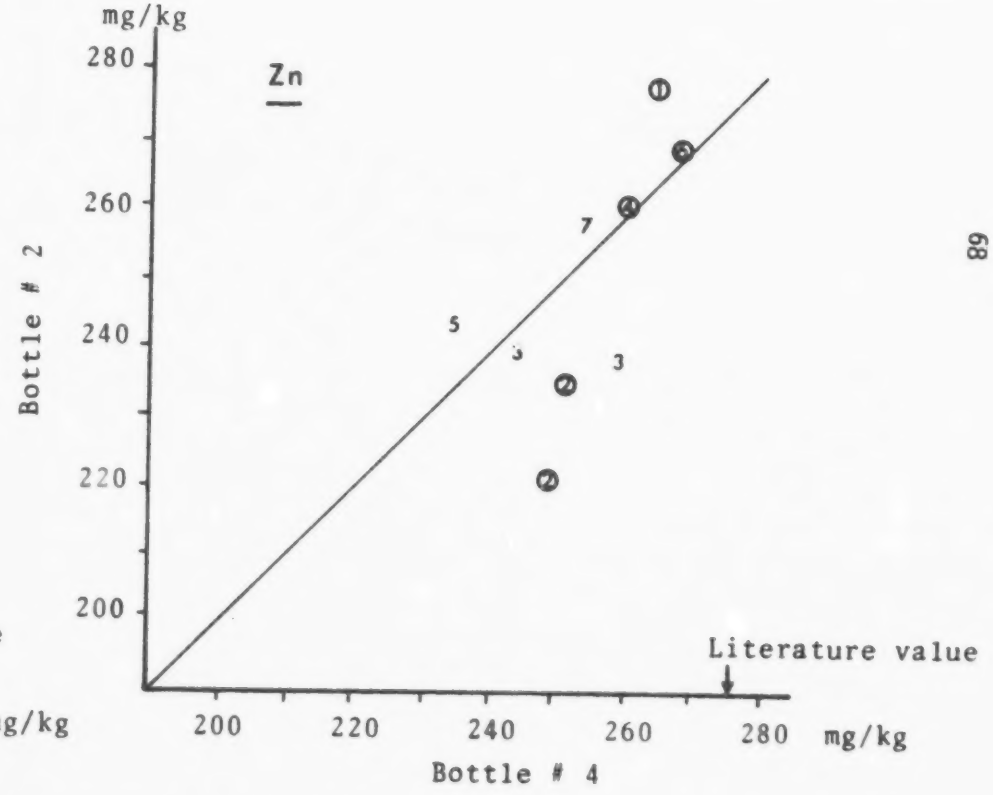
The results for WQB-2 are displayed in Figures 2.22 and 2.23. The same general pattern emerges. Laboratories that were having difficulties with MAG-1 had the same problems with WQB-2. The higher absolute concentrations of the elements of interest in WQB-2 helped normalize the distribution of reported values around the recommended value. Here, again, the measurable cadmium results were reported only by four laboratories. Laboratory #1 had both precision and accuracy problems with this material (Figure 2.22). The other generalization is that the reported values for zinc are all below the recommended value (Hunter, 1980).



Laboratory results for WQB-2. Bottle # 2 vs Bottle # 4. Circled numbers indicate laboratory used HF digestion.

Figure 2.22





Laboratory results for WQB-2. Bottle # 2 vs Bottle # 4. Circled numbers indicate laboratories using HF digestion.

Figure 2.23

The data presented here serve to point out which of the reporting laboratories is having quality control problems. Follow-up on these data should ensure that the improvement in quality of results, which has been noted between round robin 1 and round robin 2, will continue.

One of the problems in the past has been the availability of good, reliable, standard reference materials. It is expected that soon such materials would be available from sources such as the National Research Council of Canada (NRC, 1980) for both inorganic and organic parameters. The future round robins will make use of these reference materials.

In conclusion, it is strongly urged that all federally funded contracts must include a clause pertaining to quality control. The participation and satisfactory performance in quality control/blind check sample round robins must be made obligatory for prospective contractors.

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2.9 REFERENCE MATERIALS FOR MARINE TRACE ANALYSIS

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The Marine Analytical Chemistry Standards Program (MACSP) was established by the National Research Council of Canada in 1976 to meet present and future needs for standards relevant to chemical analyses of marine materials. It is our objective to act as a lead group and provide a central facility for reseach on and development of reference materials and improved analytical methods for marine chemists; to collaborate with marine chemists in developing reference materials and standards, their maintenance and distribution; and to help organize and assist in interlaboratory calibration studies.

The importance of reference materials in establishing the accuracy of analytical data for marine samples cannot be overemphasized. The use of incorrect analytical measurements can be potentially disastrous. An incorrectly high report for a toxic component may delay or prohibit dredging of a harbour, leading to economic and social difficulties for entire communities; and an incorrectly low reported level of a toxic component will lead to environmental damage, and perhaps damage to the human community relying on that environment for economic well-being.

The following discussion will fall into three sections: materials presently available, materials ready for distribution, and other projects underway and planned.

Two marine sediment reference materials for the determination of trace metals are available. BCSS-1 was collected from the Baie des Chaleurs and MESS-1 from the Miramichi River estuary. The sediments were freeze-dried, then sieved through 120 mesh screens and homogenized using facilities of the Canada Centre for Mineral and Energy Technology, Ottawa.

The materials were bottled (MESS-1, 65 g/bottle, and BCSS-1, 80 g/bottle), then gamma-ray sterilized by Atomic Energy of Canada Limited. Analyses for the trace metal and other inorganic constituents of the sediments were done by the MACSP group located in the Division of Chemistry, NRC, Ottawa. Levels were determined by as many independent methods as possible, including GFASS, ICP emission spectrometry, and isotope dilution spark source mass spectrometry. These data were compared with data from selected external laboratories with recognized expertise in sediment analyses. This work was completed early in 1981, and the materials made available for distribution. A copy of the original announcement is included in the following pages.

The MACSP program will soon release three marine sediment reference materials for the determination of polychlorinated biphenyls (PCBs). Two materials (HS-1 and HS-2) were collected from geographically distant harbours in Nova Scotia, the other (CS-1) is a carbonaceous clay collected from the Laurentian Channel. We gratefully acknowledge the assistance of the Bedford Institute of Oceanography which made such a collection possible during the course of an already busy cruise.

These three sediments were freeze-dried, and HS-1 and HS-2 passed through 100 mesh screens. CS-1 was sufficiently fine to be canned without sieving. The sediments were homogenized for a number of days in a cement mixer modified and cleaned to minimize the risk of contamination. They were then subsampled to approximately 200 gram amounts in cleaned cans. Each batch yielded over 500 cans.

Analyses of three samples each, from ten randomly selected cans, were carried out by packed column chromatography using electron capture detection. The results provided evidence of the homogeneity of the reference materials and established preliminary data on PCB levels. In November 1981, samples were sent to three laboratories with recognized expertise in the analysis of PCBs. If this intercomparison confirms our results, the samples of CS-1, HS-1, and HS-2 will be available for distribution.

Two types of information will be provided for each of these reference materials. The first will be the usual method-dependent, semi-quantitative results from packed-column chromatography/ECD analyses. Since PCBs are a complex mixture, results reported by individual laboratories will reflect the type of column packing employed, the peaks chosen for quantification, the identity of the standard, i.e., Aroclor 1254 vs. 1260, etc., and the batch of standard used. Because the reference materials are natural samples, undoubtedly altered over time in the environment, their PCB content does not exactly resemble the composition of any standard commercial mixture, thus the usual analysis can only be semiquantitative. Nevertheless, by careful description of the method used and standards employed, the reference materials should be very useful as practical quality control samples, helping analysts avoid sample handling and calculation problems which can easily lead to serious analytical errors.

The second type of analytical data will be quantitative. Using individual known components of PCBs as standards, and combining capillary gas chromatography with mass spectrometry and electron capture detection techniques, the concentration of as many components as possible will be described. This work will probably not be completed before starting distribution of the samples, but the data will be made available as they are obtained. It is anticipated that regulations which specify allowable levels for individual, toxic PCB compounds will eventually be implemented. If so, this reference material should help establish accuracy for analyses then required.

The Marine Analytical Standards Program has several other reference materials in preparation and planning stages. A seawater sample has been collected near Bermuda with the help of the Chemical Oceanography group in the Bedford Institute of Oceanography. The samples were being bottled and analyzed for trace metal levels by the MACSP members in the Division of Chemistry, NRC, Ottawa. Assuming homogeneity and storage criteria are met, samples will be available in mid-1982.

Two marine sediment reference materials for determination of polycyclic aromatic hydrocarbons (PAHs) are planned. We are improving our competence in PAH analysis in preparation for the needed homogeneity testing and analysis. Methods used will include gas chromatography, liquid chromatography, and mass spectrometry. It is projected that materials with known levels of PAHs can be available early in 1983.

The Committee on Marine Analytical Chemistry, whose members represent users of marine analytical data in government, industry, and universities, and who advise the MACSP on future goals and objectives, has proposed other projects now being considered. These include preparation of trace metals in marine organisms, perhaps fish or algal tissue, and a suggestion that the MACSP become more involved in organizing and conducting interlaboratory intercalibration exercises. If we do the latter, since NRC is not a regulatory agency, our main goal would be to assist participating laboratories to attain the level of expertise and competence they would deem needed to allow them to meet their own objectives in marine chemical analysis. NRC may also provide samples to regulatory agencies to help them carry out quality assurance programs.

It then remains the role of the MACSP to work to:

1. improve the general level of competence of marine analytical work, and improve analytical methodology;
2. provide reference materials with analyses and in matrices relevant to present and future needs; and
3. assist in interlaboratory activities that will enable individual laboratories to better meet their own needs for marine chemical analyses.

National Research Council
Canada

Marine Analytical
Chemistry Standards
Program

Conseil national de recherches
Canada

Programme de standards
de chimie analytique
marine

TABLE 2.10

For Reference

MARINE ANALYTICAL CHEMISTRY STANDARDS

In 1976, the National Research Council of Canada established this program in support of analytical chemistry aspects of marine science. A recommendation to do so had been made by the Canadian Committee on Oceanography at its 62nd meeting in June, 1975.

In this program, the National Research Council seeks the continuing advice of a Committee on Marine Analytical Chemistry representing chemists active in research on analytical chemistry and of government, university and commercial laboratories applying analytical chemistry in marine science.

National Research Council staff at the Atlantic Research Laboratory, Halifax, N.S., and the Division of Chemistry, Ottawa, Ontario, work in support of this program. Much is done in cooperation with other laboratories and through contracts.

Reference Materials:

An important aspect of the Marine Analytical Chemistry Standards Program is the preparation and supply of reference materials. The purpose is to aid analysts and to improve the accuracy of methods through intralaboratory and interlaboratory comparisons of results.

Enquiries and comments are invited. Correspondence should be addressed to:

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National Research Council Canada
Conseil national de recherches Canada

Marine Analytical Chemistry Standards Program
Programme de standards de chimie analytique marine

January, 1981

Table 2.11

MARINE SEDIMENT REFERENCE MATERIALS

TRACE METALS AND INORGANIC CONSTITUENTS

The Marine Analytical Chemistry Standards Program of the National Research Council of Canada announces the availability of two marine sediment reference materials, MESS-1 and BCSS-1.

These materials were obtained from the Gulf of St. Lawrence (MESS-1 from the Miramichi River estuary and BCSS-1 from the Baie des Chaleurs). They were freeze-dried, screened to pass a No. 120 (125µm) screen, blended, bottled and radiation sterilized.

Reliable values are available for the trace metals (<0.1%) Be, V, Cr, Mn, Co, Ni, Cu, Zn, As, Sb, Cd, Hg and Pb, and for the matrix and minor constituents C, Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, S, Cl, K_2O, CaO, TiO_2 and Fe_2O_3. Values for other constituents are given for information purposes.

In general, the trace levels in BCSS-1 are less than those in MESS-1 (e.g. Cd: 0.25 and 0.59; Pb: 22.7 and 34.0 µg/g respectively).

The bottles contain about 65 grams of MESS-1 and 80 grams of BCSS-1.

They are available from the

Marine Analytical Chemistry Standards Program
Chemistry Division
National Research Council
Montreal Road
Ottawa, Canada K1A 0R9

The cost is $150 for the pair or $80 individually (Canadian funds in Canada, U.S. funds elsewhere), payable to the Receiver General for Canada (NRC).

For further information write to Dr. Shier Berman at the above address, or telephone (613) 993-2359.

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Table 2.11 (Cont'd.) January, 1981

The following two tables give those constituents for which reliable values have been established. Reliable values are based on results of determinations by at least two independent methods of analysis. The uncertainties represent 95% tolerance limits for an individual sub-sample. That is, 95% of samples, 500 mg or greater, from any bottle would be expected to have concentrations within the specified range 95% of the time.

Trace Elements - µg/g

	MESS-1	BCSS-1
Antimony	0.73 ± 0.08	0.59 ± 0.06
Arsenic	10.6 ± 1.2	11.1 ± 1.4
Beryllium	1.9 ± 0.2	1.3 ± 0.3
Cadmium	0.59 ± 0.10	0.25 ± 0.04
Chromium	71 ± 11	123 ± 14
Cobalt	10.8 ± 1.9	11.4 ± 2.1
Copper	25.1 ± 3.8	18.5 ± 2.7
Lead	34.0 ± 6.1	22.7 ± 3.4
Manganese	513 ± 25	229 ± 15
Mercury	0.171 ± 0.014	0.129 ± 0.012
Nickel	29.5 ± 2.7	55.3 ± 3.6
Vanadium	72.4 ± 5.3	93.4 ± 4.9
Zinc	191 ± 17	119 ± 12

Matrix and Minor Constituents - percent

	MESS-1	BCSS-1
C	2.99 ± 0.09	2.19 ± 0.09
Na_2O	2.50 ± 0.15	2.72 ± 0.21
MgO	1.44 ± 0.09	2.44 ± 0.23
Al_2O_3	11.03 ± 0.38	11.83 ± 0.41
SiO_2	67.5 ± 1.9	66.1 ± 1.0
P_2O_5	0.146 ± 0.014	0.154 ± 0.016
S	0.72 ± 0.05	0.36 ± 0.05
Cl	0.82 ± 0.07	1.12 ± 0.05
K_2O	2.24 ± 0.04	2.17 ± 0.04
CaO	0.674 ± 0.064	0.760 ± 0.074
TiO_2	0.905 ± 0.028	0.734 ± 0.024
Fe_2O_3	4.36 ± 0.25	4.70 ± 0.14

2.10 NEAR-BOTTOM SEDIMENT SUSPENSIONS MEASURED BY SEDIMENT TRAP

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Introduction

The port of Saint John experiences the largest yearly amount of regular dredging and dumping of any port in the Atlantic region of Canada. Maintenance dredging of shipping channels and docks requires 500,000 m^3 of dredging in a normal year and expansion of facilities occasionally adds to this quantity. For the last 20 years this dredged harbour sediment has been deposited in 20 m of water at the Black Point dump site near the harbour entrance. Recently there have been concerns that this dumping may be affecting the benthic environment in which local fisheries are carried on. The concerns can be divided into two areas, physical and chemical. The possibility has been raised by fishermen that the dumped sediment may be altering the physical environment by raising near-bottom suspension concentrations, and by changing the bottom sediment quality through more rapid deposition throughout the outer harbour area. Also, it has been suggested that industrial effluent in the dredging areas may be contaminating dredge spoil. As part of an investigation of these questions, the Regional Ocean Dumping Advisory Committee initiated funding of this study, which provided data bearing on both these questions through the monitoring of sediment traps for a period of one year.

Methods

The sediment traps used consisted of acrylic cylinders 8 cm in diameter and 40 cm in height, closed at the bottom (Figure 2.24). These were mounted on concrete pads which were placed at four positions in the harbour (Figure 2.25). The moorings were connected by rope to a buoy at the surface for periodic retrieval. At intervals of two weeks, weather permitting, moorings were brought to the surface and the tubes capped and replaced. After shipment times of approximately 24 hr, tube contents were

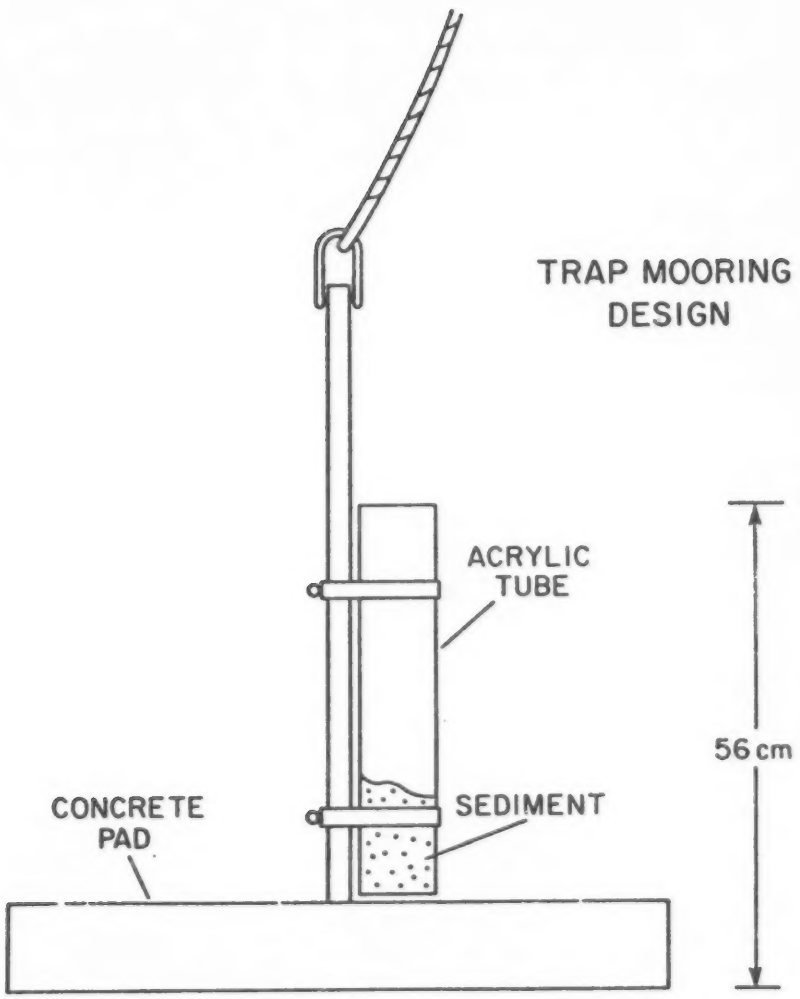

Figure 2.24
Sediment trap to measure near-bottom sediment suspensions

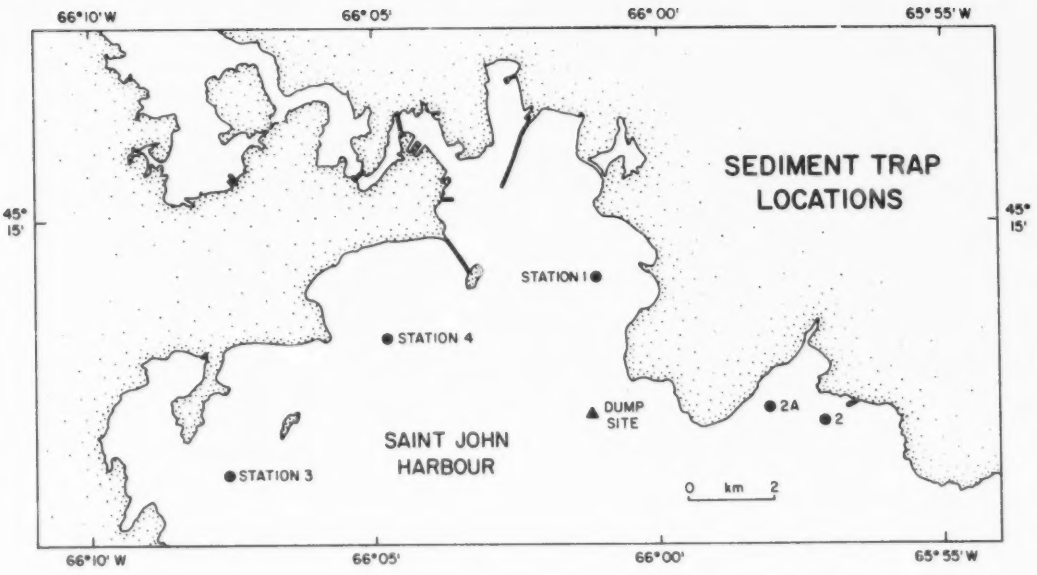

Figure 2.25

Sediment trap locations, Saint John Harbour, New Brunswick

weighed and analyzed for particle size distribution and trace metal content (mercury, cadmium, zinc, and lead) as well as organic and inorganic carbon content. For analytical methods used, see Walton (1981). For comparison with dumping activity, daily records of barge traffic to the dump site, and barge capacities, were provided by the Canadian Coast Guard in Saint John.

Sediment Trap Dynamics

Several studies have shown that sediment traps have certain limitations when used in strong curents. Hargrave and Burns (1979) tested a wide variety of trap configurations in the laboratory and in the field, and found that a high aspect ratio of height to aperture was necessary to prevent loss of trapped sediment from removal by turbulent water motion entering the trap. In their tests, traps with aspect ratios of 5 to 40 collected up to 95% of depositing sediment in a 4 to 5 cm/s current measured in water 30 cm above trap apertures. Gardner (1980) discusses the effect of high Reynolds number flow in generating turbulence at the trap mouth which causes rapid mixing of interior and exterior water. He uses this effect to explain an overtrapping phenomenon in which cylinders in strong currents trap particles at rates which may exceed local deposition by 50%. Both authors agree that high aspect ratio cylinders approximate ideal collection under the greatest variety of conditions. These experiments helped determine the cylinder dimensions for this study, which resulted in an aspect ratio of 5.

It is clear that the lower portions of the interior of the trap may contain water that is much less turbulent than outside water. Particles that may be maintained in suspension by turbulence outside the trap can readily settle inside. The upper portions of the trap may form a continuously renewed supply of particles for settling in the lower portion. The quantities obtained in the traps will therefore bear no relation to the amount of deposition of sediment in the area, but will rather be an indication of the concentration and movement of sediment particles suspended in the near-bottom currents of the harbour.

Results

Figures 2.26 and 2.27 on the following pages present the data obtained. The dates of trap placement and removal are given in the Julian system. Cadmium, mercury, lead, zinc, organic and inorganic carbon are presented as concentrations on a dry weight basis. Silt and sand modal sizes in μm were derived from Coulter Counter analysis. Trapping rate is the volume obtained over the trapping interval averaged per day, and the dumping rate is the total recorded barge volume in metric tons taken to the Black Point Dumpsite over the trapping interval, also averaged per day.

Prior to interpretation of the data, it is necessary to list several features of the record for each station. The first general observation to be made is that there are no clear consistent correlations between any of the major variables, at all stations. On the other hand, the data are not entirely scattered as most quantities show remarkably regular and gradual increases and decreases with time.

Features of the Record at Individual Stations

Station 1

The greatest rate of accumulation occurs in late December during moderate dredging and moderate tidal amplitude. A subsequent mid-winter minimum accumulation occurs during increased dredging and low tidal amplitude. Through the summer, both dredging and accumulation are low and accumulation remains low during a fall peak in dumping activity, only increasing late in the fall. Cadmium was consistently higher during the summer period of low dredging and low accumulation, as is organic carbon. Zinc remained reasonably consistent throughout the record, as did the mode size of the sediment.

FIGURE 2.26

Station 1

Set number	1	2	3	4	5	6	7	8	9	10	11
Trap interval-start date	311	325	346	1	15	33	47	64	76	98	116
Trap interval-end date	325	346	1	10	33	47	64	76	98	112	125
Cadmium conc. (mg/kg)	0.01	0.01	0.04	<0.01	<0.01	0.14	0.08	0.11	0.22	<0.01	0.09
Mercury conc. (mg/kg)	0.04	0.04	0.03	0.05	0.01	0.04	0.01	<0.01	0.03	0.02	0.01
Lead conc. (mg/kg)	14.6	11.7	14.4	10.8	25.2	39.2	30.8	18.1	23.9	17.4	24.0
Zinc conc. (mg/kg)	46.9	46.3	49.8	43.8	71.1	269.6	66.8	88.6	74.8	87.7	126
Inorganic carbon (g/kg)	2.8	2.2	1.4	2.0	3.3	4.0	3.0	4.1	3.2	4.7	4.6
Organic carbon (g/kg)	9.2	6.9	7.6	5.9	6.8	12.5	9.3	7.8	7.7	7.9	15.4
Silt mode (micron)	50	20	64	32	50	20	64	50		40	20
Sand mode (micron)	-	-	-	130	-	64	-	-		-	-
Trapping rate (ml/day)	21.6	22.2	37.1	70.6	26.6	9.1	16.6	22.1	59.6	22.7	16.4
Dumping rate (tonnes/day)	229	530	741	1251	1209	1648	1992	1312	157	0	0

Set number	12	13	14	15	16	17	18	19	20	21	
Trap interval-start date	125	141	154	168	183	203	221	241	260	276	
Trapinterval-end date	141	154	168	183	203	221	241	260	276	294	
Cadmium conc. (mg/kg)	0.25	0.18	0.09	0.26	0.30	0.23	0.09	0.04	-	0.31	
Mercury conc. (mg/kg)	0.13	0.61	0.09	0.06	0.06	-	-	-	-	-	
Lead conc. (mg/kg)	34.7	23.8	25.2	30.6	29.2	32.0	18.9	29.8	-	24.8	
Zinc conc. (mg/kg)	28.7	100	92.1	127	180	130.8	92.3	76.8		71.8	
Inorganic carbon (g/kg)	5.4	12.8	3.4	5.2	4.8	10.1	3.2	3.7	-	4.7	
Organic carbon (g/kg)	12.2	1.19	9.0	10.2	12.2	4.5	8.0	11.5	-	8.6	
Silt mode (micron)	40		40	40	40		40				
Sand mode (micron)	-		-	-	-		-				
Trapping rate (ml/day)	7.6	5.7	6.4	4.6	3.5	3.7	4.5	4.7	-	38.8	
Dumping rate (tonnes/day)	0	0	0	0	0	0	290	1551	2352	552	

Station 2

Set number	1	2	3	4	5	6	7	8	9	10	11
Trap interval-start date	311	325	346	1	15	33	47	64	76	98	116
Trapinterval-end date	325	346	1	10	33	47	64	76	98	112	125
Cadmium conc. (mg/kg)	0.09				<0.01	0.12	0.10	0.11	0.12	<0.01	<0.01
Mercury conc. (mg/kg)	0.05				0.03	0.05	0.03	0.02	0.02	0.02	0.02
Lead conc. (mg/kg)	18.8				23.0	32.5	33.7	16.3	20.1	19.2	22.8
Zinc conc. (mg/kg)	63.9				69.1	91.0	74.2	55.9	73.8	81.7	125
Inorganic carbon (g/kg)	2.5				3.4	3.7	5.0	5.6	3.3	4.4	5.9
Organic carbon (g/kg)	10.2				8.0	12.3	12.5	8.4	7.1	9.6	9.7
Silt mode (micron)		40			50	32	50	50	32	40	32
Sand mode (micron)		-			-	-	-	80	100	-	-
Trapping rate (ml/day)		11.7			57.5	9.1	52.0	48.1	48.3	24.6	11.8
Dumping rate (tonnes/day)	229	530	741	1251	1209	1648	1992	1312	157	0	0

Set number	12	13	14	15	16	17	18	19	20	21	
Trap interval-start date	125	141	154	168	183	203	221	241	260	276	
Trap interval-end date	141	154	168	183	203	221	241	260	276	294	
Cadmium conc. (mg/kg)	0.10	0.30	0.07	0.16	0.13	0.69	0.21			0.11	
Mercury conc. (mg/kg)	0.08	0.89	0.05	0.09	0.08	-	-			-	
Lead conc. (mg/kg)	28.3	29.7	34.1	22.9	24.5	26.5	14.9			24.8	
Zinc conc. (mg/kg)	165.3	181.1	118.2	60.7	58.3	64.7	62.7			45.7	
Inorganic carbon (g/kg)	4.8	9.3	3.4	2.5	2.1	6.7	2.1			4.7	
Organic carbon (g/kg)	9.9	1.1	8.4	4.9	6.6	20.4	10.6			8.6	
Silt mode (micron)	40	40	40	50	60	50	-			60	
Sand mode (micron)	128	-	-	160	200	-	130			200	
Trapping rate (ml/day)	8.3	5.3	12.5	27.2	15.9	9.7	19.7			22.0	
Dumping rate (tonnes/day)	0	0	0	0	0	0	290	1551	2352	552	

FIGURE 2.27

Station 3

Set number	1	2	3	4	5	6	7	8	9	10	11
Trap interval-start date	311	325	346	1	15	33	47	64	76	98	116
Trap interval-end date	325	346	1	10	33	47	64	76	98	112	125
Cadmium conc. (mg/kg)	0.01				0.04	0.84	0.22	0.08	0.10	<0.01	<0.01
Mercury conc. (mg/kg)	0.04				0.01	0.03	0.02	<0.01	0.03	0.01	0.01
Lead conc. (mg/kg)	13.2				21.7	40.5	24.2	9.7	13.1	19.1	20.1
Zinc conc. (mg/kg)	49.5				67.1	302.1	44.5	61.8	57.4	74.1	92.6
Inorganic carbon (g/kg)	2.8				2.7	1.8	4.5	2.6	2.5	4.3	7.6
Organic carbon (g/kg)	6.0				3.5	12.0	19.3	6.5	6.2	7.3	8.4
Silt mode (micron)	50				50		32	64		20	20
Sand mode (micron)	100				-	-	130	130		203	-
Trapping rate (ml/day)	15.9				25.2	9.1	21.8	47.2	57.1	32.1	28.2
Dumping rate (tonnes/day)	229	530	741	1251	1209	1648	1992	1312	157	0	0

Set number	12	13	14	15	16	17	18	19	20	21	
Trap interval-start date	125	141	154	168	183	203	221	241	260	276	
Trap interval-end date	141	154	168	183	203	221	241	260	276	294	
Cadmium conc. (mg/kg)	0.11	0.08	0.04	0.11		0.37	0.08	<0.002		0.12	
Mercury conc. (mg/kg)	0.11	0.39	0.06	0.07		-	-	-		-	
Lead conc. (mg/kg)	31.5	25.3	21.5	27.3		30.1	17.4	30.8		29.1	
Zinc conc. (mg/kg)	191	95.7	113.3	63.2		70.9	82.3	53.7	52.4	67.5	
Inorganic carbon (g/kg)	5.3	8.2	3.1	2.5		4.1	3.0	3.1		2.2	
Organic carbon (g/kg)	10.5	1.2	7.1	6.0		7.6	6.5	7.8		7.9	
Silt mode (micron)		40	50	50				20	25		
Sand mode (micron)		-	100	100				80	64		
Trapping rate (ml/day)	12.3	4.9	29.5	9.9		7.1	5.8	13.7	18.5	16.0	
Dumping rate (tonnes/day)	0	0	0	0	0	0	290	1551	2352	552	

Station 4

Set number	1	2	3	4	5	6	7	8	9	10	11
Trap interval-start date	311	325	346	1	15	33	47	64	76	98	116
Trap interval-end date	325	346	1	10	33	47	64	76	98	112	125
Cadmium conc. (mg/kg)	0.28	0.04	0.02	<0.01	<0.01	0.14	0.07	0.13	0.32	0.11	0.04
Mercury conc. (mg/kg)	0.05	0.05	0.03	0.02	0.01	0.03	0.01	0.02	0.02	<0.01	0.03
Lead conc. (mg/kg)	18.8	13.2	22.7	12.8	18.9	32.2	26.9	16.6	15.6	13.1	22.6
Zinc conc. (mg/kg)	103.1	45.0	51.0	54.6	61.4	99.6	61.8	80.1	53.0	67.2	122.0
Inorganic carbon (g/kg)	1.6	3.0	2.7	2.8	2.5	3.4	3.9	3.4	1.6	2.3	4.0
Organic carbon (g/kg)	6.0	7.5	8.7	17.9	4.0	10.7	10.1	9.6	22.4	6.7	9.3
Silt mode (micron)		32	64	50	50	50	80	80	50		25
Sand mode (micron)		-	-	-	-	-	-	-	-		-
Trapping rate (ml/day)	10.3	33.1	22.7	87.1	40.9	3.8	22.4	60.9	72.6	47.3	
Dumping rate (tonnes/day)	229	530	741	1251	1209	1648	1992	1312	157	0	0

Set number	12	13	14	15	16	17	18	19	20	21	
Trap interval-start date	125	141	154	168	183	203	221	241	260	276	
Trap interval-end date	141	154	168	183	203	221	241	260	276	294	
Cadmium conc. (mg/kg)	0.13	0.09	0.06	0.18		0.35	<0.05	<0.002	<0.002	0.14	
Mercury conc. (mg/kg)	0.12	0.59	0.05	0.10		-	-	-		-	
Lead conc. (mg/kg)	26.1	19.4	21.8	31.3		28.9	16.9	25.2	13.3	24.2	
Zinc conc. (mg/kg)	97.4	79.7	66.1	87.1		75.5	84.6	57.2	44.9	64.1	
Inorganic carbon (g/kg)	3.5	12.1	3.0	5.3		4.6	3.3	2.2	2.3	2.1	
Organic carbon (g/kg)	10.1	1.2	7.5	10.5		9.6	8.3	8.5	3.2	5.6	
Silt mode (micron)	25	25	50	32			40	50	64	64	
Sand mode (micron)	-	-	-	-			-	-	-	-	
Trapping rate (ml/day)	8.5	6.3	26.9	12.7		5.9	4.4	20.9	23.5	16.0	
Dumping rate (tonnes/day)	0	0	0	0	0	0	290	1551	2352	552	

Station 2

Moorings were repeatedly lost during the fall of 1979, but the existing data show an increase from November to a high value in January followed by the typical February minimum, rising again in March and April at the time of the dredging peak. The rate is low in summer with a significant peak in July during no dumping. The rate rises again in the fall of 1980. Cadmium and organic carbon were highest through the low dredging and accumulation of the summer period. Zinc concentration rose in May during no dredging and low accumulation. The size spectrum developed a secondary peak of coarse sediment in July.

Station 3

Three moorings were lost in the early portion, but the record of accumulation rate generally follows that of Station 2 through the February minimum and the spring peak, a secondary peak in early July, and a rise again in the fall of 1980. Organic carbon shows an increase at the same time as the dredging peak, and cadmium shows an anomalously high value during the February accumulation minimum which is accompanied by a coarsening of the sediment size spectrum.

Station 4

Accumulation rate again showed the typical fall rise during moderate dredging, the February minimum during major dredging, and the spring peak a month after the peak in dumping activity, with a secondary midsummer peak and a rise in the fall of 1980. Organic carbon concentration was somewhat higher during the spring period of decreasing accumulation, accompanied by a rise in cadmium values. Zinc concentrations and the grain size characteristics were notably uniform through the record.

Comparisons Between Stations

Station 2 at Mispec is considered to be a control station. Due to the logistics of trap tending it was not possible to locate it completely outside the possible range of influence of the dump site, but was felt to qualify as a control site because of the lobster fishery which appears to be continuing successfully in that area. Observed sediment suspensions in this area can be taken as not incompatible with a benthic fishery.

(tonnes/day)

In general, the accumulation rates in all locations show a remarkably consistent pattern of variation through the year. All show the early winter rise in trapping rate followed by the extreme minimum in February, the spring peak followed by generally lower rates in summer. The highest rates recorded occur at Station 4, followed by Station 1. The closest correspondence between dumping rates and accumulation rates exists at Station 2, but even this correspondence disappears during the February minimum in accumulation rate. While there was a slight tendency for Station 4 to have the largest accumulation, every station had the largest on at least one occasion. Similarly, trace metal results and carbon concentrations do not show large and consistent differences between stations. Only grain size spectra provide a clear distinction between different suspension regimes, with Stations 2 and 3 showing secondary peaks from material of grain size 100 to 200, while Stations 1 and 4 are dominated by material of mode size from 20 to 70. Stations 1 and 4 are both inside the harbour mouth while 2 and 3 are closer to the open Bay of Fundy.

Interpretation

The trace metal results are the most readily interpreted features of the data. By comparison with a survey of the benthic sediments of Saint John Harbour (Bezanson and Kranck, unpublished) it is seen that zinc concentrations are simply typical of the general background in the bottom sediments in the area of the trap locations. The study mentioned showed that cadmium and mercury levels were too low throughout the harbour to serve as significant tracers of sediment movement, and the levels of these metals shown here correspond to those low values. Zinc was shown by that study to serve as a useful tracer. The average levels of zinc for the year are 104 mg/kg at Station 1, 92 mg/kg at Station 2, 93 mg/kg at station 3, and 80 mg/kg at Station 4, supporting the conclusion of the previous study that the major source of zinc in the harbour sediments is the embayment of Little River, near Station 1, rather than the dump site which is closest to Station 2. The residual circulation has been shown by Neu to be clockwise within the study area, and these zinc concentration averages

decrease in clockwise order from Station 1. These values are also somewhat higher than the range in outer harbour benthic sediments of 40 to 80 mg/kg, showing some enrichment of zinc in suspensions over deposited sediments.

The interpretation of accumulation rates requires some caution due to the dependence of trapping efficiency on both particulate concentration and the Reynolds number of the flow at the trap aperture. Neu's 1958 survey showed typical bottom velocities ranging from 12 to 17 cm/s near Station 1, 30 to 50 cm/s near Station 2, 15 to 21 cm/s near Station 3, and 18 to 27 cm/s near Station 4. Current conditions are roughly similar at all stations except Station 2 which has about double the current speed of the other areas. Particulate concentrations may therefore be somewhat lower there than would be indicated by direct correspondence with accumulation rate, but the effect may be small. The primary element to be examined in the record of accumulation rate is its relationship to the rate of dumping at Black Point. If the record is examined coarsely by dividing into winter and summer periods, there is a distinct correspondence between all stations and the dumping rate. Both are high in winter and low in summer. However, the sampling frequency permits month-by-month examination, and this shows discrepancies. All stations experience an extreme minimum in February during heavy dumping. The March dumping peak has decreased almost to zero by the time of the April accumulation peak. Secondary summer peaks of 30 to 50% of maximum accumulation rate occur during no dumping at all. Neu has shown that residual current speeds in the outer harbour are such that circulation times between the dump site and trap stations would be a few days at most. Material suspended during dumping and transported completely in suspension would cause an immediate rise in accumulation rate, and this can therefore be ruled out except for Station 2. Alternatively, material originating at the dump site could slowly move on the bottom through repeated erosion and redeposition. In the record, Station 2 shows an immediate rise while 2, 3, and 4 increased gradually to simultaneous peaks one month later, occurring during greatly decreased dumping.

For dumped sediment to produce these peaks in accumulation rates, it must remain initially at or near the dump site and Station 2, and be transported later to produce elevated suspended concentrations at Station 2, 3, and 4 simultaneously. This final possibility is reduced by the February minimum and by the strength of currents in the vicinity of the dump site. Fine sediment, especially when disturbed by dumping, is not stable in the dump site region (Station 2) where current stresses normally exceed erosion threshold values determined in laboratory studies (Odd and Owen 1972). As well, there seems to be no variation in accumulation rate due to proximity to the dump site. The grain size spectra at Station 2, downstream from the dump site in the residual circulation, do show a trend toward lower mode during the higher cumulation rates in the winter dredging period, but also show a still lower mode during the February minimum. Station 3, next downstream in the residual circulation, shows an elevation of mode toward the spring peak, as does Station 4, but not 1. Zinc values, somewhat elevated in dredged sediments, drop toward the peak.

A plot of the variation of tidal amplitude with time shows tidal energy varying more rapidly than the accumulation record, with no consistent correlation.

Conclusions

While many elements of the suspended sediment regime in Saint John Harbour remain unexplained, the sediment trap data indicate that the deposition of dredged sediment at Black Point dump site, up to rates of 2000 m^3 per day, do not add to the near-bottom particulate concentrations as measured by sediment traps. This conclusion is supported by:

1. trace levels of zinc in the trapped sediment,
2. the similarity of accumulation rates at all stations,
3. differences in time of maxima of dumping and of accumulation, and
4. grain size spectra showing dominance of the sediment regime by the dynamic conditions of the Bay of Fundy.

Acknowledgements

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2.11 OVERVIEW OF TRACE METAL LEVELS IN EASTERN CANADIAN COASTAL AND ESTUARINE SEDIMENTS*

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Introduction

This report summarizes most of the knowledge on the levels, distribution, and chemical partition of trace metals (Zn, Cu, Pb, Co, Ni, Cr, V, Hg, As, Se, and Cd) in the marine sediments of the Bay of Fundy; the Gulf of St. Lawrence including the St. Lawrence estuary and the Saguenay fjord; and Baffin Bay (Figure 2.28). It is based on a series of geochemical studies undertaken from 1970 to 1981. (Loring 1975, 1976a, b, 1978, 1979a, b, 1981).

Field and Laboratory Methods

Sediment samples were obtained at 42 locations in Baffin Bay, at 257 locations in the Gulf area, and at 84 locations in the Bay of Fundy with a Van Veen ($0.1 m^2$) grab.

Total trace element concentrations (Hg, Zn, Cu, Pb, Co, Ni, Cr, Cd, and V) as well as acetic acid (25% v/v) soluble and insoluble Zn, Cu, Pb, Cd, Co, Ni, Cr, and V were determined from a dried sample by the atomic absorption techniques described by Loring and Rantala (1977), Rantala and Loring (1980).

The coefficients of variation in USGS standard mud MAG-1 were found to be 10% for Co, 7% for Ni, 2% for Cr, 3% for V, 2% for Zn, 19% for Pb, 14% for Cu and 5% for Cd (Rantala and Loring 1978, 1980). Arsenic was determined under contract using a colorimetric determination in which 0.2 gram samples were digested in a HNO_3-$HClO_4$ mixture for three hours.

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* Part of a paper (ICES W.G. MS 1982/3) tabled and presented at the ICES Working Group "Marine Sediments in Relation to Pollution - Lowestoft, U.K. February 18, 1982.

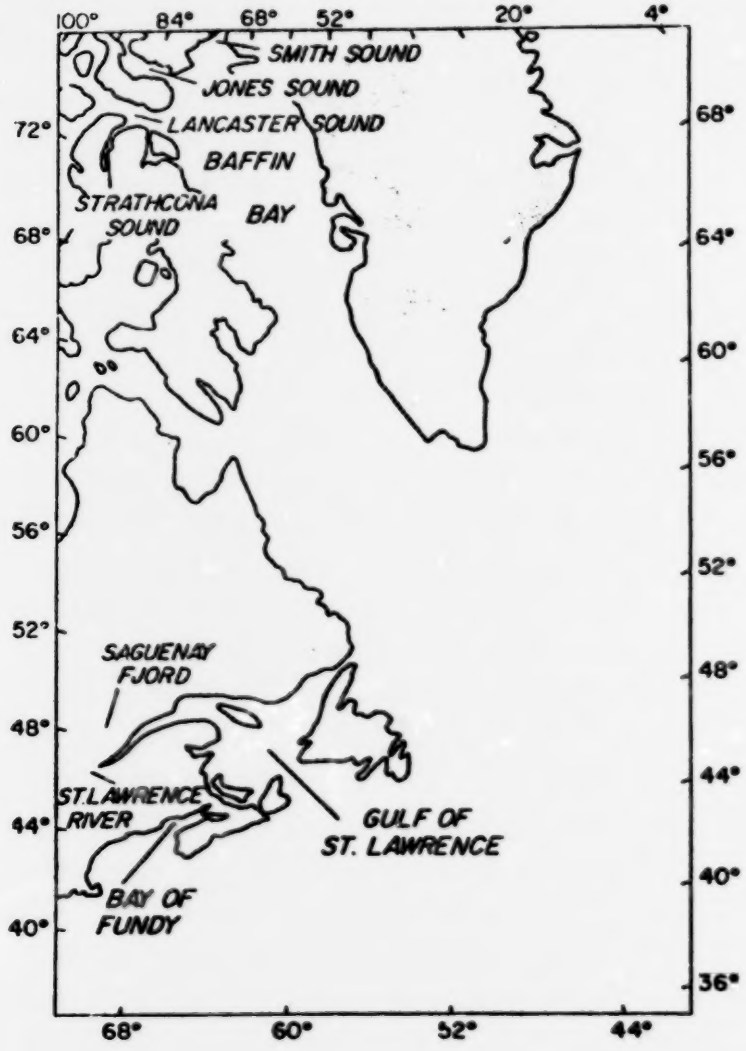

Figure 2.28
Regional place names Eastern Canada

Selenium was also determined under contract using a standard flameless atomic absorption technique. Mercury was determined by the cold vapor atomic absorption method comparable to that described by Hatch and Ott (1968).

Heavy Metals in Coastal and Estuarine Sediments

Abundance

Total elemental concentrations measured in the sediments are Zn 8-215 ppm, Cu 3-81 ppm, Pb 8-66 ppm, Co 3-42 ppm, Ni 2-160 ppm, Cr 8-352 ppm, V 4-168 ppm, Hg 0.02-9.5 ppm, As 1-36 ppm, Se 0.11-1.29 ppm and Cd 0.01-0.63 ppm (Table 2.12).

Textural and Regional Distributions

Metal concentrations vary regionally and with sediment texture. On the average (Table 2.12), the concentrations of Zn, Cu, Pb, Co, Ni, Cr, V, Hg and As are low in the sands and generally increase significantly ($P = 0.01$) with decreasing grain size of the sediments so that the higher concentrations occur in the sandy muds and muds. Exceptions to this are noted in Table 2.12. Regionally, dispersal patterns of the individual elements are very comparable to each other as they relate closely to the particle size and distribution pattern of the sediments. For example Figure 2.29 shows that the highest concentrations of Zn in the St. Lawrence sediments are found in fine-grained sediments classified as pelites or muds that occur at the mouth of the St. Lawrence River, in the Saguenay Fjord and in the central part of the submarine troughs of the open Gulf and lower St. Lawrence estuary. Lower Zn concentrations (50 ppm) occur in the sandy shelf sediments of the Gulf.

Dispersal patterns for most of the other elements were found to be comparable to Zn in the Gulf of St. Lawrence. They have been combined into one illustration (Figure 2.30) that shows the relative distribution of high, medium, and low concentrations in the Gulf as well as the Bay of Fundy. There are certain exceptions to the general pattern, however, that refer to the accumulation of high concentrations of certain elements at specific locations in the region. These are indicated in Figure 2.29 by their chemical symbol. For example, Figure 2.29 shows that the highest concentrations of Hg, Zn, as are found at the head of the Saguenay Fjord,

Table 2.12

Trace metal concentrations (ppm) in Eastern Canadian marine sediments. **

Location	No. of Samples	Zn	Cu	Pb	Co	Ni	Cr	V	Hg	As	Cd	Se
St. Lawrence Estuary Upper	20	106	17	25	14*	18	66	102*	.28	5(19)+	.10	.46(19)
	Range	70-215	9-44	14-39	10-19	8-29	39-95	84-120	.10-.49	1-11	.01-.36	.12-1.01
Saguenay Fjord	20	109	22	37	15	22	74	111	2.51	15(17)	.23(19)	.50(18)
	Range	59-145	6-33	15-66	10-20	9-36	49-97	67-149	.16-9.50	2-36	.01-.42	.14-1.29
St. Lawrence Estuary Lower	49	96	20	28	14	26	83	97	.37	6(46)	.19	-
	Range	52-185	6-52	15-46	7-22	7-42	37-120	52-147	.12-.86	2-14	.03-.63	-
Gulf of St. Lawrence	130▲	67	22	19	12	29	74	89	.20	5(117)	.24(60)	-
	Range	18-116	3-76	8-40	3-28	2-160	8-158	4-168	.03-.60	2-11	.06-.45	-
Bay of Fundy	83	51	15	20	12	15	57*	70	.03	8	.22*	.17
	Range	18-104	5-32	8-42	4-27	3-46	15-352	27-136	.02-.07	4-15	.03-.58	.11-.36
Arctic Coastal and Sound	25	45	20	18	10	19	57	79	.05	-	.13(23)	-
	Range	17-83	4-42	11-33	6-14	5-71	16-139	47-156	.02-.08	-	.05-.31	-
Baffin Bay Deep Sea	13	77	47	23*	26	51*	84*	115	.07	-	.13	-
	Range	34-106	12-81	12-32	11-42	19-94	56-109	63-155	.04-.11	-	.05-.29	-

▲ Does not include samples from Lower Southern Gulf of St. Lawrence.

* No significant ($P<0.01$) direct relationship.

+ Numbers in brackets refer to number of samples averaged.

** Analysis R.T.T. Rantala

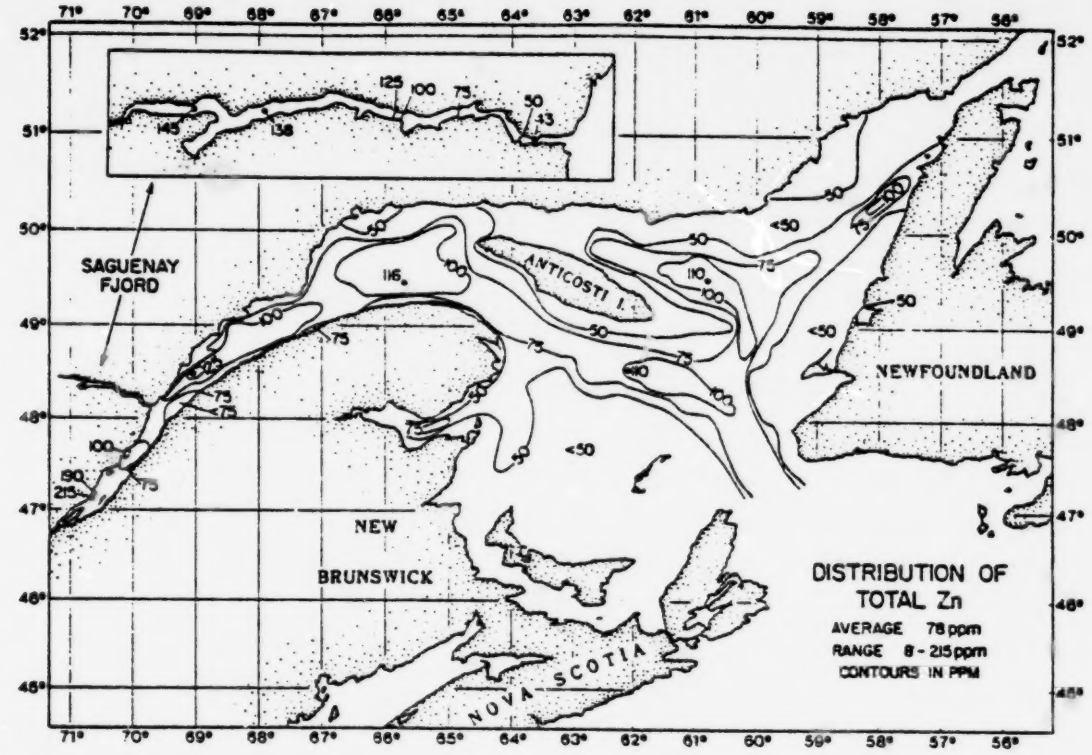

Figure 2.29 Distribution of Zn in the surface sediments of the Gulf of St. Lawrence region.

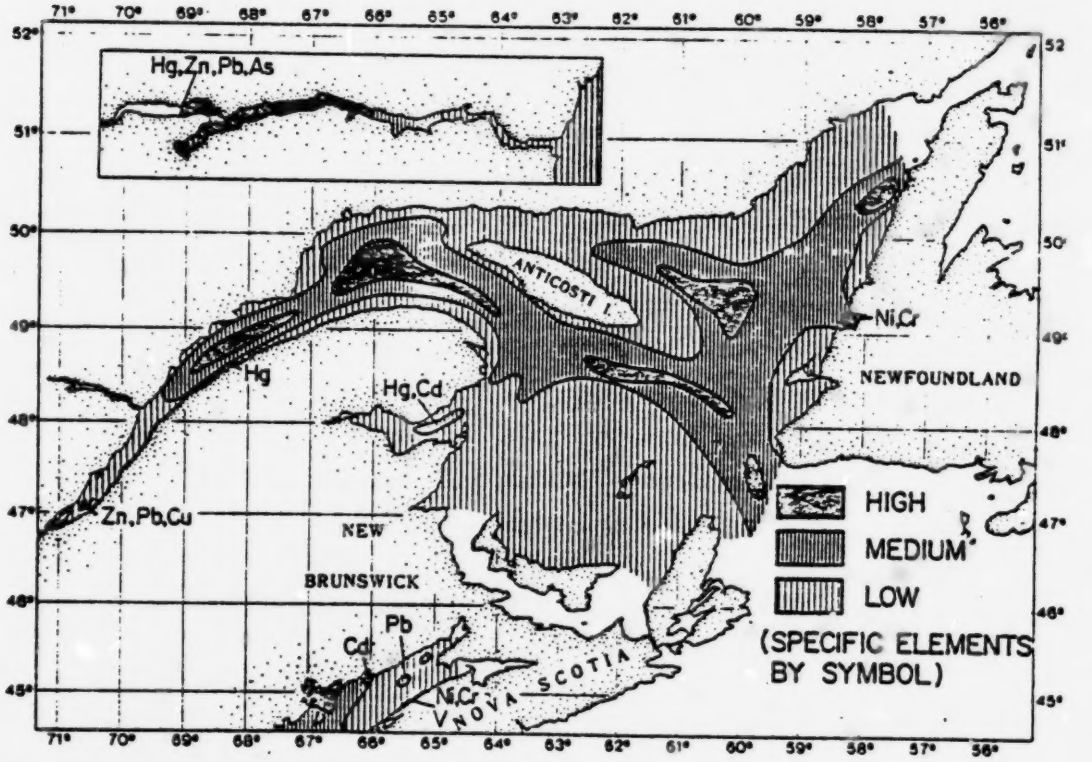

Figure 2.30 Relative distribution of the high, medium and low concentrations of Zn, Cu, Pb, Co, Ni, Cr, V, As, and Cd in the surface sediments of the Gulf of St. Lawrence region.

Zn, Pb and Cu and the mouth of the St. Lawrence River, Cd and Hg in the Bay of Chaleur, Ni and Cr in the open Gulf, and Pb and Cd in the Bay of Fundy. The locations of these metal anomalies at or near known sources of urban and industrial wastes, and mineralized areas serve to identify the nature and magnitude of the real and potential effects of metal contamination in the region (Figure 2.31).

In the Arctic region, sediment samples from coastal areas (water depths less than 500 m) and from the Arctic Sounds contain lower average concentrations of the metals than those found in the sediments in water depths exceeding 500 m in Baffin Bay (Table 2.12).

In the coastal areas and sounds, the concentrations of elements with the exception of Pb and Hg increase significantly ($P < 0.01$) with increasing mud content of the sediments. Pb varies, however, inversely with mud content. Offshore in Baffin Bay, the concentrations of Zn, Cu, Co V and Hg increase with water depth with the highest concentrations of these elements occurring in the muds from water depths exceeding 1000 m.

Evaluation of the extent of metal contamination is relative in any given area and between regions, and depends on the mineralogy, grain size of the material, and its natural and anthropogenic sedimentary history. Since it is clear that total elemental concentrations of the material in eastern Canadian estuarine and coastal areas are very dependent on grain size, it is necessary at least to make our regional comparisons with texturally equivalent sediments, particularly the fine-grained sediments which contain the highest concentrations. Table 2.13 shows that Zn, Cu, Pb, Hg and As concentrations vary regionally whereas Co, Cr, Cd, Ni, V concentrations remain relatively constant between each area. The relatively high concentrations of metals are found in the upper St. Lawrence estuary (Zn, Cu, Pb), the Saguenay fjord (Hg, As, Pb, Zn), and Baffin Bay deep sea (Cu, Co, Ni) sediments. Medium and lower concentrations of these metals are found in the lower St. Lawrence estuary (Zn, Hg), open Gulf of St. Lawrence (Zn, Cu, Pb, Hg, As), the Bay of Fundy (Zn, Cu, Pb, Hg, As), and Arctic region, and are usually relatively constant between each region.

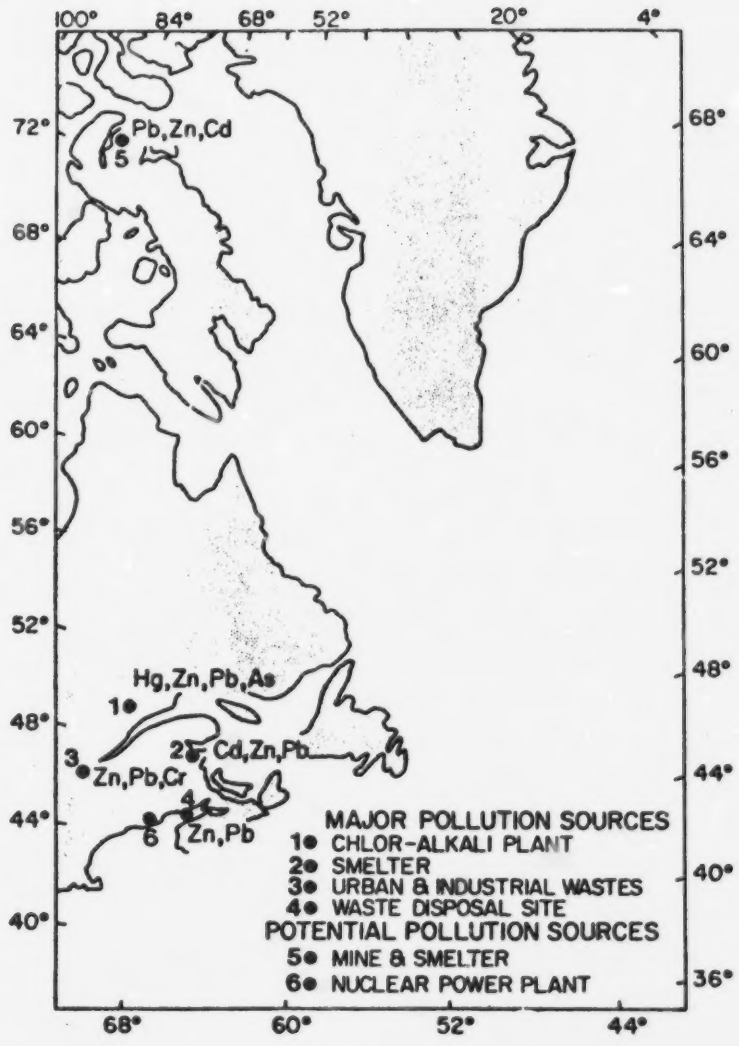

Figure 2.31

Major and potential pollution sources for Eastern Canada marine sediments.

Chemical Partition and Potential Bio-availability of the Metals

Although high levels of metals in sediments are a general indication of industrial and urban contamination, total metal concentrations are a poor means of assessing the potential or actual availability of a given element to the biota as a whole or to specific organisms. This is because the largest part of the total metal concentrations is usually locked up physically and/or chemically in detrital particles and minerals, and is not directly available to the biota (Loring 1976a). From an immediate biological and environmental viewpoint, it may be only important to consider the "reactive" part that is loosely bound in a physical and/or chemical sense either to inorganic and organic portions of the particles, in interstitial solutions, or in easily soluble minerals in the sediments. It is now being recognized that it is necessary to estimate mainly by chemical and physical partition that part of the total elemental concentrations that is potentially available as a whole, and through selective experiments that which is available to individual organisms.

Chemical Partition

A number of chemical extractants either singly or in combination have been used for assessing the "available fraction of different metals in sediments" (Hirst, 1962; Chester and Hughes, 1967; Luoma and Jenne, 1976; Agemian and Chau, 1976; Salomons and De Groot, 1978).

In most cases, the different authors have found varying degrees of selectivity for the various extractants. Of all the extractants, we have employed a weak (25% v/v) acetic acid to make an assessment of the "available" metal concentrations in the Eastern Canadian coastal sediments (Loring, 1981). This method was chosen because it is one of the weakest chemical treatments that can be effectively used to remove a certain part of the total metal concentration in the sediments from site and forms that could be potentially available to the biota.

Table 2.13

Trace metal concentrations (ppm) in fine grained* marine sediments of Eastern Canada.**

Location	No. of Samples	Zn	Cu	Pb	Co	Ni	Cr	V	Hg	As	Cd	Se
St. Lawrence Estuary Upper	3	185	36	34	15	27	92	97	.38	6(2)†	.26	.56
	Range	151-215	27-44	30-39	13-17	26-29	89-95	93-100	.32-.46	-	.13-.36	.12-.90
Saguenay Fjord	13	130	27	48	16	28	83	121	3.66	21(11)	.25	.51
	Range	117-145	24-33	30-66	12-20	22-36	65-97	76-149	.99-9.50	11-36	.15-.35	.14-1.29
St. Lawrence Estuary Lower	29	115	24	30	17	33	99	110	.45	7(27)	.22	-
	Range	76-185	16-52	15-46	13-22	19-42	68-120	65-147	.15-.86	3-14	.05-.58	-
Gulf of St. Lawrence	71	84	25	21	14	36	87	105	.22	6(62)	.26	-
	Range	18-116	5-76	11-40	4-28	4-104	30-124	38-155	.05-.60	2-11	.07-.30	-
Bay of Fundy	13	77	19	30	15	22	73	95	.06	9(11)	.24	.22(10)
	Range	52-104	15-23	19-42	11-20	14-37	51-91	72-136	.03-.09	6-13	.13-.33	.13-.34
Arctic - Coastal and Sound	16	64	29	17	14	26	67	95	.05	-	.16	-
	Range	40-106	12-46	11-30	6-37	10-77	38-97	54-156	.02-.08	-	.06-.31	-
Baffin Bay Deep Sea	7	91	66	24	34	65	91	136	.09	-	.13	-
	Range	59-106	28-81	12-32	15-42	30-94	63-109	97-155	.06-.11	-	.10-.20	-

* >70% by weight <53μm in diameter

† numbers in brackets refer to number of samples averaged

**Analysis R.T.T. Rantala

The acid treatment (25% v/v acetic acid) is used to remove elements held in carbonate and easily soluble amorphous compounds of Mn and Fe, in ion-exchange positions, and weakly attached to organic matter. This treatment leaves the lattice structure of the silicate minerals intact and does not attack the very resistant iron and manganese oxide minerals (Loring and Nota, 1968).

Preliminary results also demonstrate that this method is reproducible when used in different laboratories.

Potential Bio-availability of Metals

Chemical partition of the sediments from the various regions shows (Table 2.14) that 7-35% of the total Zn, 5-21% of the total Cu, 12-27% of the total Pb, 3-25% of the total Co, 7-29% of the total Ni, 1-11% of the total Cr, 3-23% of the total V and 28-74% of the total Cd (arctic only) occur in the acetic acid soluble fraction, referred to here as the non-detrital fraction. This small, but perhaps biologically significant non-detrital fraction may represent some proportion of the element that was initially leached from the source rocks or supplied in dissolved form from industrial sources. Some of the non-detrital contributions may also be derived from available ions released during diagenetic alterations, held in soluble minerals, and (or) held in surface and interstitial positions of the material. The remainder (26-99%) of the total metal concentration (depending on the individual metal) is acid insoluble and presumably not directly available to the biota. It represents that part of the total metal concentration bound up in the lattices of various sulphide, oxide, and silicate minerals and acid insoluble compounds of Fe and Mn.

From these data it is clear that environmental assessment of the impact of heavy metals on the biota must take into account the "potential bioavailability" of the elements rather than just their total contents in the sediments. If this is even approximately true, then relatively higher levels in the environment might be tolerated. For example, if it is determined that the metal is securely locked up on its carrier mineral or compound and is in equilibrium with its physiochemical environment, such as sulfides in the reducing zone or Cr securely locked up in chromite, then it may not be directly available to the biota. If on the other hand, the

Table 2.14

The non-detrital (acid soluble) contribution as a percentage of the total element content of eastern Canadian coastal sediments.[e]

Location	No.	Zn	Cu	Pb	Co	Ni	Cr	V	Cd
St. Lawrence River	(2)	41[c]	30[c]	24[c]	23[c]	—	—	—	—
Upper St. Lawrence estuary	(20)	17-39[c]	17[a,c]-20[b]	17[a]-26[c]	14[a,b]-20[c]	13[a,b]-19[c]	4[a]-11[c]	5[a]-10[c]	—
Saguenay Fjord	(19)	14[a]-29[c]	14[b]-21[c]	12[d]-25[c]	8[a]-25[b]	11[a]-29[b]	2[a]-9[d]	6[a]-23[d]	—
Lower estuary	(49)	18[b]-20[a,b,c,d]	13[c]-20[a]	15[b]-19[d]	18[b,c]-24[d]	16[c,d]-23[a]	2-5[d]	6[a]-18[d]	—
Open Gulf	(127)	8[c]-9[a,b,d]	7[b]-13[a]	18[c]-27[d]	8[c]-13[a,d]	12[a,b]-15[c,d]	2[a,c,d]-3[b]	8[c,d]-11[b]	—
Bay of Fundy	(66)	9[c]-14[a,b]	5[c,d]-18[b]	18[c]-27[d]	7[c]-12[d]	7[b]-9[c]	1[b,c,d]-2[a]	3[a,c]-4[b,d]	—
Arctic	(41)	7[a]-11[d]	6[a]-17[d]	18[a]-19[d]	3[d]-10[a]	8[a]-14[d]	1[d]-2[a]	5[d]-8[a]	28[a]-74[c]

Sediment type.

a. Muddy sand; 5-30% pelite (<0.05 mm),>70% sand (2 mm-0.05 mm).
b. Very sandy pelites (muds); >30% sand, >30% pelite.
c. Sandy pelites (muds); 5-30% sand, >70% pelite.
d. Pelites (muds); <5% sand, >95% pelite.
e. Analyst R.T.T. Rantala

metal is weakly attached to the surface of the particles or is in the form of a compound easily digested by an organism then lesser quantities could be tolerated in the environment and in any material such as dredge spoils artificially introduced into the environment.

Acknowledgement

Sedimentological and chemical analyses, and data compilation were very capably preformed by R.T.T. Rantala.

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2.12 OCEAN DUMPING RESEARCH IN THE PACIFIC REGION

H. Nelson

Abstracts of Papers Presented at the Ocean Dumping Workshop
Institute of Ocean Sciences, Patricia Bay, B.C.
(December 2, 1981)

OCEAN DUMPING RESEARCH IN THE PACIFIC REGION

1. Effects of Silt and Organic Debris on Eggs and Larvae of Pacific Cod (Gadus macrocephalus).
   Scientific Authority: M. Nassichuk
   Contractor: E.V.S. Consultants

2. Further Investigation of the Occurrence and Production of Tetramethyllead in Marine Sediments.
   Scientific Authority: J.A.J. Thompson
   Contractor: Dobrocky SEATECH Limited

3. The Identificaton of Biologically Available Cadmium by Selective Chemical Extraction Techniques Availability of Cadmium from False Creek Sediments.
   Scientific Authority: R.W. Macdonald
   C.D. Levings
   Contractor: E.V.S. Consultants

4. Review of the Presence and Environmental Impact of Cadmium in Marine and Freshwater Systems.
   Guest Speaker: D. MacGregor
   Contaminants Control Branch, Ottawa

5. A Statistical Analysis of Benthic Invertebrate Sampling in Tuktoyaktuk Harbour, N.W.T.
   Scientific Authority: B. Wilson
   W. Fenton
   Contractor: Arctic Laboratories Limited

6. Accumulation of Polynuclear Aromatic Hydrocarbons (PAH) from Water and Sediment by Marine Invertebrates

Guest Speaker: D.W. McLeese
Fisheries and Environmental Sciences
Department of Fisheries and Oceans
Biological Station, St. Andrews, N.B.
Canada EOG 2XO

7. A Review of Criteria for Evaluating Ocean Dumping Permit Applications with Recommendations for Future Monitoring Requirements

Scientific Authority: R. Kussat, E.P.S.
Contractor: E.V.S. Consultants

8. A Review of the Ecological Consequences of Dredging and Dredge Spoil Disposal in Canadian Waters

Scientific Authority: C.D. Levings

9. Ocean Dumping Research in the Atlantic Region

Guest Speaker: A.R. McIver
A/Chairman, RODAC
Atlantic Region
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Effects of Silt and Contaminated Sediment on Eggs and Larvae of Pacific Cod (Gadus macrocephalus)

E.R. McGreer and D.R. Munday

Fertilized eggs of the Pacific cod (Gadus macrocephalus) were exposed to different concentrations of silt, and a marine sediment contaminated with heavy metals and polychlorinated biphenyls. Each sediment concentration was tested under two experimental conditions: 'quiescent' and 'in suspension.' Quiescent tests were designed to simulate burial of eggs by deposited dredge spoil. Effects measured included mortality in three different stages of embryonic development, percent hatchability, and time to 50% hatch. The toxicity of test sediments to newly hatched larvae of Pacific cod, and the ability of larvae to ingest each sediment, were also assessed.

Mortalities were consistently higher in the early germ ring egg stage than in other stages tested. Elevated mortalities compared to controls were observed at the highest silt concentrations of 22 and 30 g/L in tests with silt in suspension. Increased mortalities with contaminated sediments occurred at concentrations of 15 g/L under quiescent conditions, and 7.5 and 15 g/L with the sediment in suspension. The presence of silt in quiescent tests increased hatchability compared to controls. Concentrations of contaminated sediment above 2 g/L resulted in a sharp decrease in hatchability in all test conditions. A slight increase in hatching time over controls was apparent with increasing silt concentrations; however, no obvious differences in time to 50% hatch were observed for similar concentrations of silt and contaminated sediment. Sediments were not toxic to cod larvae in concentrations tested, and there was no apparent difference in the percentage of larvae feeding on silt or the contaminated sediment.

Production of Lead Alkyls in Marine Sediments

J.A.J. Thompson

The potential for microbial conversion of inorganic lead (II) and organolead (IV) was studied in two B.C. coastal sediments of widely differing types. In an anoxic closed-vial experiment, samples from Saanich Inlet (high organic carbon) and Alice Arm (mine tailings, low organic carbon) containing lead (II) (nitrate, sulfide, or acetate) were incubated at 15° for up to four weeks. Analysis of head-space gases employing GC-AA techniques at eight times during the experiment indicated that conversion to tetramethylead (TML) was inconsistent and time-independent. In a second two-week experiment, employing flow-through conditions under anoxic and oxic conditions, TML (to 3.3 $\pm 0.4\ \mu g$) was isolated in hexane when either sediment was inoculated with trimethyllead (IV) acetate. Production of TML was approximately threefold greater under anoxic conditions than in air. No TML was detected when sediments containing $Pb(NO_3)$ or inorganic lead were incubated for the same period. Results of this work support earlier conclusions regarding the unimportance of methylation in the mobilization of lead in marine sediments.

Experimental Investigation into the Accumulation of Cadmium by the Polychaete Worm 'Capitella capitata' and the bivalve 'Macoma balthica'

B.J. Reid, R.W. Deverall, P.M. Chapman, and A.W. Maynard

The bioavailability of sulphide-bound cadmium phases to the bivalve Macoma balthica and the polychaete Capitella capitata was determined. Sixty-day laboratory experiments were conducted using ^{109}Cd and ^{115}Cd-labelled sediments from False Creek, B.C., under constant temperature and salinity conditions. Seawater and biota were removed for isotope counting at intervals of 2, 4, 6, 8, 16, 32, and 60 days. Sediments from the uptake experiment were chemically analyzed at the beginning and end of the experiment using a selective extraction scheme. Laboratory data were compared with measurements of background cadmium levels in selected False Creek biota.

Measurable levels of ^{109}Cd in M. balthica were only determined on day 60; similarly, measurable release of ^{109}Cd to the overlying water was only determined on day 60 of the experiment. ^{115}Cd was not detected in biota or seawater over 60 days. Results of the sediment characterization and selective extraction suggested that cadmium sulphide phases were not available for uptake by biota due to their lack of solubility.

Review of the Presence and Environmental Impact of Cadmium in Marine and Freshwater Systems

D. MacGregor

A brief overview of the analysis and speciation of cadmium in sediments was presented. Existing ocean dumping criteria for cadmium were compared critically with levels of cadmium in a range of uncontaminated and contaminated media and biota. Emphasis was placed on the distinction between bioaccumulation and ecotoxicity and on case studies in which the presence of cadmium has produced measurable toxic effects.

A Statistical Analysis of Benthic Invertebrate Sampling in Tuktoyaktuk Harbour, N.W.T.

Arctic Labs Ltd.

In 1980 Arctic Labs conducted a combined chemical, physical, and biological oceanographic survey in Tuk Harbour, N.W.T., on behalf of Dome Petroleum Limited. Included was the collection of benthic invertebrate samples. The statistical analysis of these samples was completed under a contract issued by EPS in Yellowknife.

The benthos sampling stations were selected to provide good harbour coverage and the greatest density of sampling in the area, within the harbour, where the most intense dredging activity would occur. Some stations were placed in areas where few benthic organisms would be expected to survive the dredging project. These stations provided an inventory of smothered species and a 'before dredging' baseline against which future re-

colonization could be compared. Other stations at varying distances from the dredging ativities served as monitors for possible future changes in community structure following completion of dredging. Because the benthic communities of Tuk Harbour must endure very large seasonal variations in their environmental surroundings, samples were collected on two occasions - shortly after breakup and toward the end of the open-water season - to provide information on seasonal variability. The collection of samples at two separate times also provided an estimate of sampling variance.

Accumulation of Polynuclear Aromatic Hydrocarbons (PAH) from Water and Sediment by Marine Invertebrates

D.W. McLeese

Sources of PAH to the marine environment include creosote oil used to preserve wood, petroleum spillage, and long-range aerial transport of PAHs derived from combustion. PAHs are relatively insoluble in water and are readily transported to sediments in association with particulate matter.

Some PAHs are carcinogens.

Dredging of harbours and harbour channels and disposal of the spoils redistributes sediments that may contain high levels of PAH.

The bioavailability of PAH was investigated by exposing clams (Mya arenaria), shrimp (Crangon septemspinosa), polychaete worms (Nereis virens), and mussels (Mytilus edulis) to sea water containing a mixture of five PAH compounds and also to contaminated sediment. Data for clams and worms are summarized.

The animals were exposed for 96 hr to flowing sea water at 10°C containing a mixture of PAH compounds. The compounds were phenanthrene (4 µg/L), fluoranthene (2.4 µg/L), pyrene (28 µg/L), triphenylene (0.4 µg/L), and perylene (0.3 µg/L). After 96 hr the animals were maintained in uncontaminated water for two weeks.

Sediment contaminated with PAH was collected from a site in northeastern New Brunswick that received wastes from a wood-treatment plant. Animals were exposed to a 4-cm layer of contaminated sediment for 96 hr and then transferred to uncontaminated sediment.

Clams exposed to five PAH compounds in water had relatively high uptake rate constants (k_1 of 8.2 to 36/hr), and low excretion rate constants (k_2 of 0.0064 to 0.0011/hr). Calculated bioconcentration factors (BCF) ranged from 1,280 (phenanthrene) to 10,000 (perylene).

Clams exposed to sediment contaminated with PAH showed similar uptake and excretion patterns for the five PAH compounds. The BCFs, calculated in relation to the concentration of the PAH in surficial water, ranged from 890 (phenanthrene) to 3900 (triphenylene) and were smaller than the BCFs from water exposure.

The BCF increased with increasing complexity and molecular weight of the PAH compunds.

A Review of Criteria for Evaluating Ocean Dumping Permit Applications with Recommendations for Future Monitoring Requirements

E.R. McGreer and D.E. Konasewich

Generally, the review showed a trend toward the use of biological testing to assess possible ecological impacts of dredge spoil disposal and the inadequacies of relying solely on chemical criteria (e.g. bulk chemical content) to assess dumping impacts. The current parameters used in the Canadian System 2000 Ocean Dumping Data Base were evaluated, and suggestions made for modifications and additions to those presently listed. Specific modifications included the need for more accurate reporting of field sampling methods and chemical analytical data. Trends in monitoring data from selected dredge and dump sites in the Pacific Region were reviewed but trends were not well defined due to the paucity of time-series data, and differences in sampling methods and analytical techniques employed. Recommendations for future monitoring included evaluating long-term effects of spoil disposal, and standardization of methodologies for physical, chemical, and biological sampling and analysis.

2.13 BAY OF CHALEUR DUMP SITE STUDIES - STATUS REPORT

G. Packman and K.L. Tay
EPS, Dartmouth, N.S.

During the 1981/82 fiscal year the Environmental Protection Service, Atlantic Region, in conjunction with D. Bezanson of Ocean Science and Surveys, and EPS, Quebec Region, undertook studies at the Heron Island dump site in the Bay of Chaleur.

Purpose

The primary purpose of this study was to determine if a bottom depression or 'trench' adjacent to the existing Heron Island dump site is characterized as being any less dynamic than the original dump site, and therefore more suitable for the disposal of dredged materials from Dalhousie. Previous suggestions had been made that this might be the case and therefore it was felt that some concrete data should be obtained. It was also felt that if the 'trench' site was to be used, suitable baseline information at that site should be available for future comparisons. Since dredged spoils in the Dalhousie Harbour area contain cadmium in excess of the Ocean Dumping Control Act Schedule I limit of 0.6 mg/kg, it was felt that scallops should be collected from the existing Heron Island dump site and a nearby control site so that tissue cadmium concentrations might be determined, and insights into the bioavailability of cadmium found in those spoils obtained.

Methods

To provide the required information a program was designed which included:

1. sediment physical and chemical analyses,
2. benthic community characterization, and
3. analysis of scallops from the existing Heron Island dump site and a nearby site which is being assumed, at the present time, to be a control site.

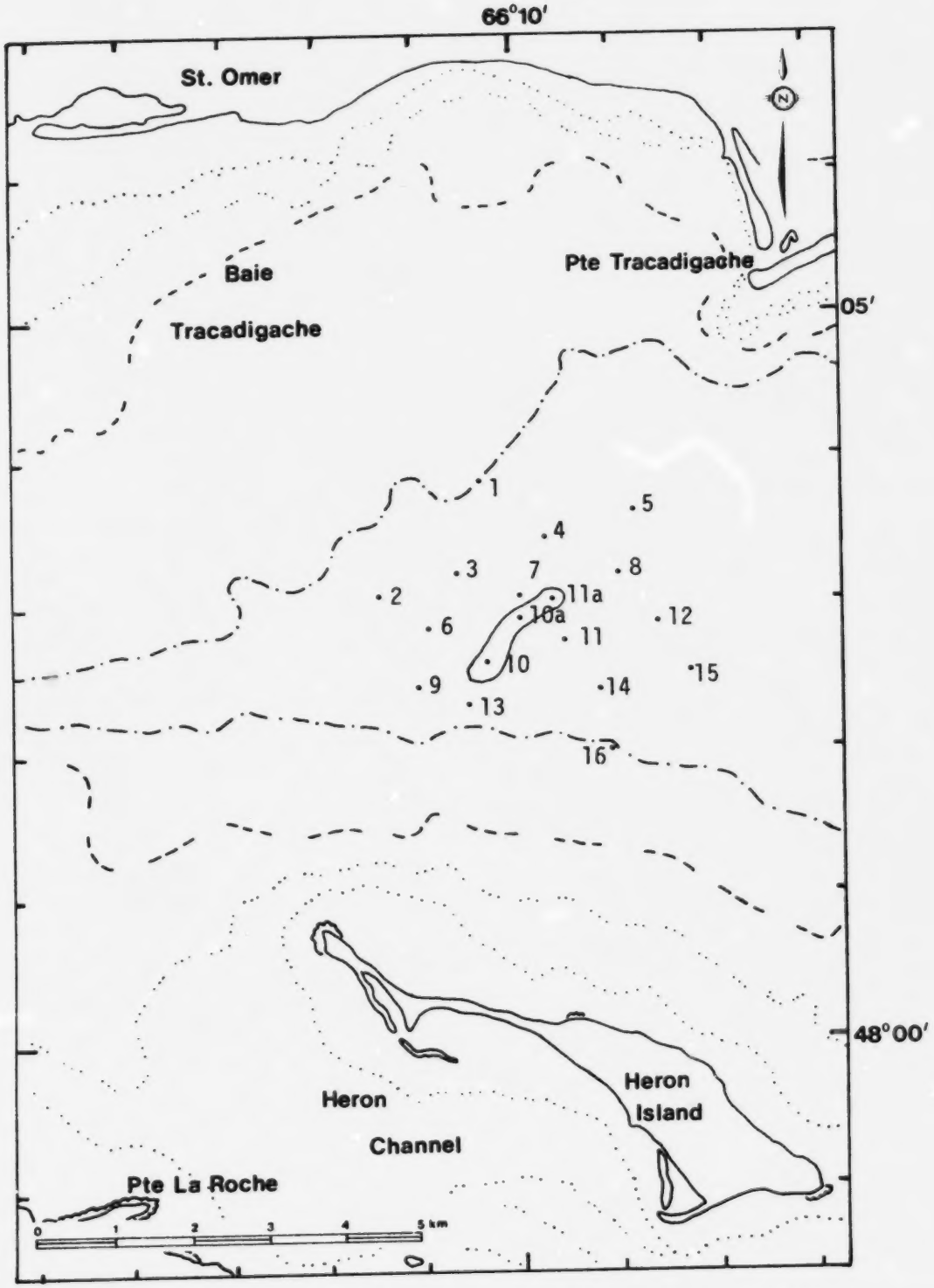


FIGURE 2.32: STATION SAMPLING GRID - BAY OF CHALEUR DUMP SITE

A station sampling grid was selected as indicated in Figure 2.32. Sampling was conducted from a local scallop dragger which had been chartered, and positions were established using horizontal sextant angles.

Samples were obtained at each station using a Peterson grab and subsampled for analysis of particle size distribution, organic carbon content, cadmium, mercury, zinc, and lead. Separate grab samples were obtained for benthic faunal identification and enumeration.

Scallops were obtained using a commercial scallop drag at the dump site and control site. After collection the scallops were permitted to depurate in clean sea water for 5 hours and then frozen for subsequent analysis.

Analyses of the scallop tissues and sediment samples for trace metals were performed in the EPS Atlantic Region Chemistry Laboratory. Sediment size analyses were performed by the Nova Scotia Research Foundation while organic carbon analyses were performed by MacLaren Plansearch. Benthic faunal sorting was carried out by a summer student, under contract, and identification work was carried out under contract by Scotia Biological.

In conjunction with the Ocean Dumping Research fund-supported work, EPS Atlantic Region let a contract to Martec Ltd. to install current meters at the existing Heron Island dump site and in the trench. These meters were in place, 1.3 m above the bottom, from November 6 to December 9 and a data report has been completed by Martec.

Results

At the present time data are available from the sediment trace metal analyses and approximately half of the scallop tissue analyses, as well as the current meter data. The data at this time are in a preliminary form, however, some ranges are available as outlined below:

Sediment trace metals

Cd	0.1	-	2.5	mg/kg
Zn	42.0	-	281.0	mg/kg
Pb	2.0	-	32.3	mg/kg
Hg	0.03	-	0.18	mg/kg

Scallop tissue cadmium

Visceral Mass	- Dump Site	2.6 - 32.0	mg/kg
	Control Site	8.7 - 26.0	mg/kg
Adductor Muscle	- Dump Site	0.3 - 0.9	mg/kg
	Control Site	0.3 - 1.8	mg/kg

Cadmium concentrations increased with increasing scallop size however a detailed trend analysis has not been performed to verify the significance of this observation. Also, the validity of the control site needs to be verified.

Current Data

On preliminary examination, there does not appear to be any great difference in the current regimes between the two sites. The average current speeds and directions were determined to be:

	Dominant Direction	Secondary Direction
Station 1 - Heron Island Site	SW - 16.9 cm/s	NE - 9.0 cm/s
Station 2 - Trench Site	WSW - 12.5 cm/s	ENE - 13.3 cm/s

Generally, the spikes in current speed at the two sites were similar but a more detailed analysis of the data is required before conclusions can be drawn.

Summary

Analyses are still underway and the data available have not yet been investigated in sufficient detail to permit conclusions to be drawn. It is expected that all data will be complete before the end of fiscal year 1981/82 and that a report will be available in 1982/83.

2.14 RESULTS OF THE 1979-1981 SPAWNING BED, PLANKTON, AND AERIAL PHOTOGRAPHIC SURVEYS OF THE MIRAMICHI BAY SPRING HERRING FISHERY, PERTAINING TO THE IMPACT OF CHANNEL DREDGING OPERATIONS

Robert A. Pottle
Biology Department, Dalhousie University
Halifax, N.S.

Introduction

The proposal of the Miramichi shipping channel dredging project in 1974 raised concern about the impact of dredging and spoil disposal upon the Miramichi region marine and anadromous fisheries, particularly those for salmon, lobster, and herring. Following the initial environmental impact and engineering studies (Philpott, 1978), a need for additional research on potential damage to these fisheries was clear.

Herring (Clupea harengus L.) return to Miramichi Bay annually in April-May and spawn in shallow water in the outer bay near the seaward end of the shipping channel and within 3.5 km of dump site C. Areas of concern for this fishery, worth $0.7 million in 1979 (Messieh et al., 1981), included direct physical damage to spawning sites, the effects of increased suspended sediment loads on the behaviour of adult herring and on the survival of herring eggs and larvae, and spatial overlap of traditional fishing areas and dredging operations.

The effects of suspended and deposited sediments on herring adult, larval, and egg stages were investigated by D.J. Wildish and have been described previously (Messieh et al., 1981). The results of the 1979-1981 field studies of herring spawning habitats and fishing gear distribution in Miramichi Bay, supervised by S.N. Messieh of the Marine Fish Divison, are briefly described below.

Research Program

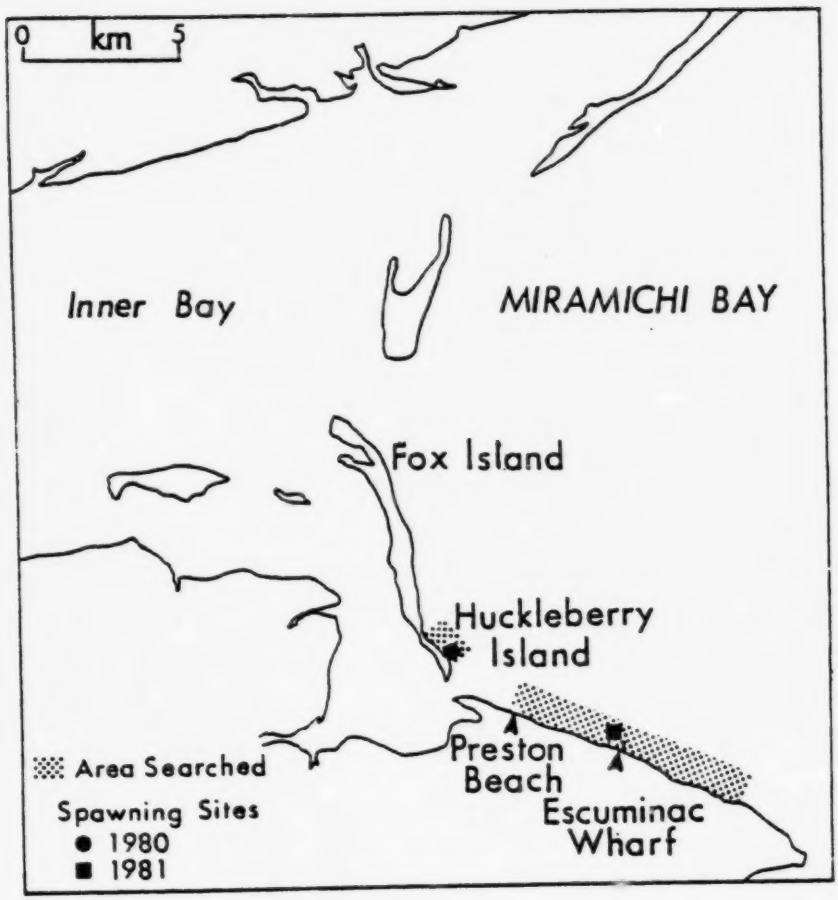
(a) 1979. In May 1979, a preliminary SCUBA survey was conducted in the inner bay at Bay du Vin, and between Fox Island and Point Escuminac

in the outer bay to determine the extent of the herring spawning areas and to identify sites with heavy egg deposition. Major spawning sites were located on the eastern side of Huckleberry Island and off Preston Beach, primarily at depths of 3 to 4 m, although eggs were found at depths of up to 8 m. Plankton tow data indicated a major concentration of herring larvae at the Huckleberry Island site, with a northward dispersal pattern parallel to the Huckleberry-Fox Island complex and through the outer bay dredging area. The dispersal pattern suggests that newly hatched larvae are initially entrained in the more saline bottom water.

Aerial photographs of gillnet distribution near Escuminac in late May indicated that the spawning area and zone of maximum fishing effort overlapped. This was confirmed by extensive aerial photographic surveys in 1980 (Messieh and Macpherson, 1981) and 1981 (Messieh and Macpherson, in preparation). There was no significant overlap of the traditional gillnet fishing areas and the dredging and disposal areas.

(b) 1980. Despite a more thorough search of the outer bay spawning area in May 1980 (Figure 2.33) only one small spawning bed, adjacent to Huckleberry Island, was located. This site was 2.0 km southwest of navigation buoy 6M and 3.5 km from the southwest corner of dump site C. Herring eggs were distributed within a surveyed 450 x 250 m area from 0.9 to 4.3 m depth, at concentrations of 0 to 28,360 eggs/m^2 (mean: 8500 eggs/m^2). Plots of egg distribution indicated that the spawning bed was somewhat larger than the sampling area (Figure 2.34 and 2.35). All eggs were attached to macrophytic algae, primarily Chondrus crispus, Phyllophora sp. and Fucus sp. Survey techniques and spawning bed habitat were described by Pottle et al. (1980).

By the end of the spring fishery, landings were approximately 57% below those recorded in 1979 and it was clear that there had been a tremendous decrease in egg deposition in the historical spawning area. Plots of gillnet distribution (Messieh and Macpherson, 1981) suggested that herring would have great difficulty in reaching shallow water due to concentrations of $\leq$150 standard nets/km^2 on and immediately seaward of the spawning sites.



Map of areas searched and location of natural and "forced" spawning beds surveyed in Miramichi Bay, N. B. in 1980 and 1981 respectively.

Figure 2.33

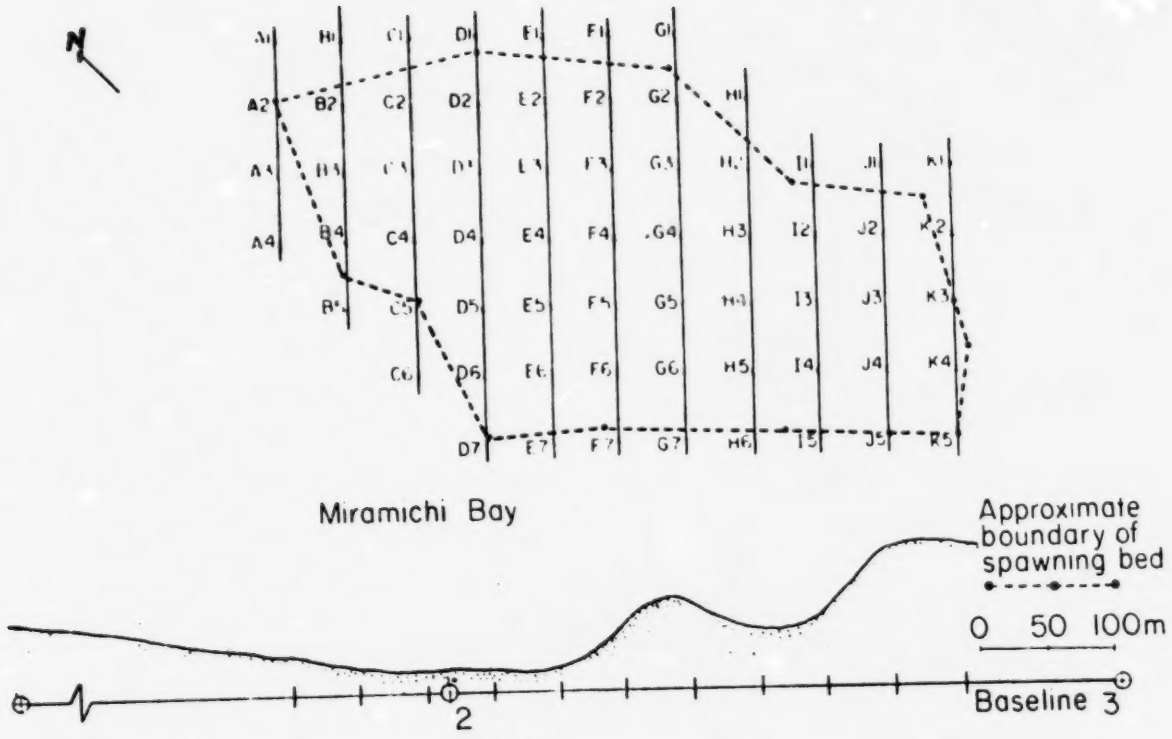
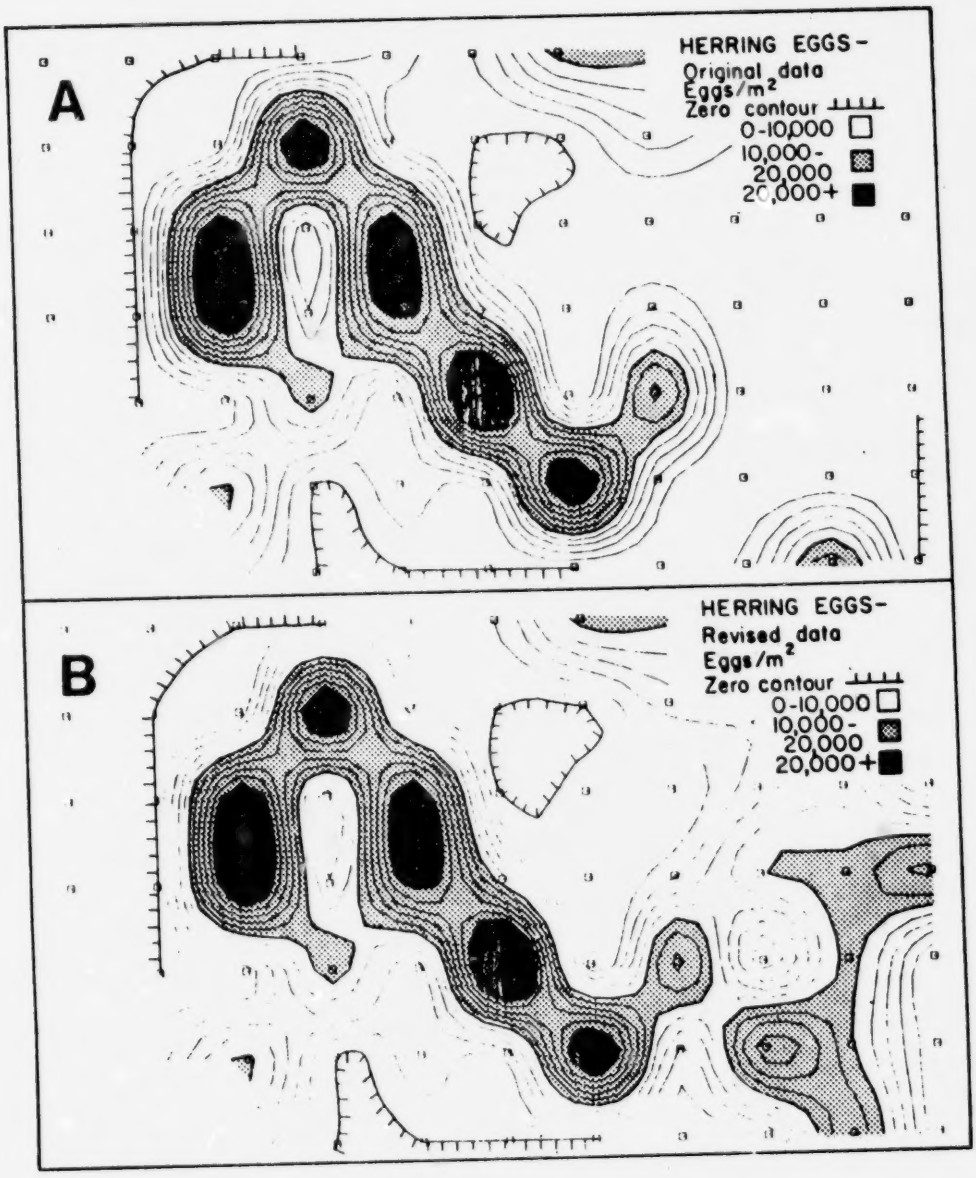


Figure 2.34

Plot of perimeter buoy locations and transect stations on the spawning bed adjacent to Huckleberry Island, Miramichi Bay, May 1980 (from Pottle et al., 1980).



Contour plots of herring egg distribution on the Huckleberry Island spawning bed (from Pottle et. al., 1980).

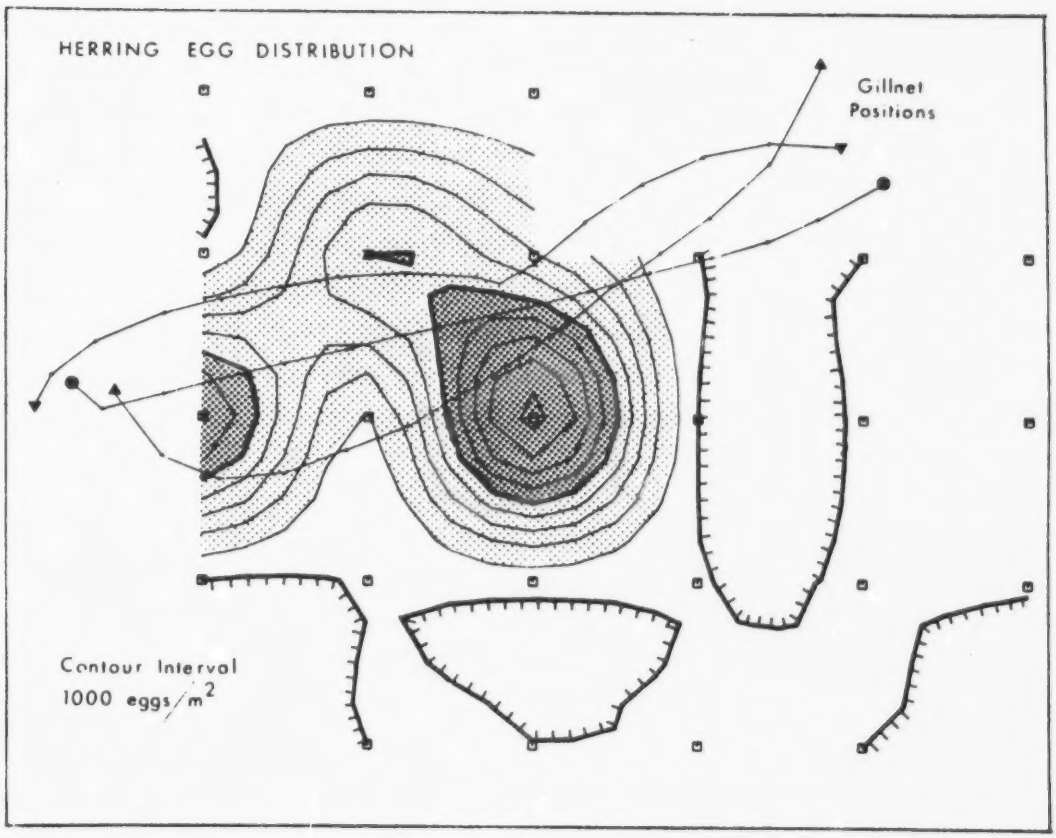
Figure 2.35

(c) 1981. A third survey was conducted by Murdoch, Pottle, and Macpherson Marine Services and Marine Fish Division personnel, in April-May 1981. Although the primary objectives were to collect additional data on spawning habitat, egg development rates, and mortality due to predation, we were to report the presence of spawning beds near the new shipping channel or dump site C, and divers were briefed to report unusual turbidity or accumulation of sediment on herring eggs or macrophytes.

No natural spawning beds were found in the historical spawning area, although a few sparse deposits of viable eggs were found adjacent to fixed gillnets in the Escuminac area. The lack of correlation between intensity of egg depositon and biomass of algal cover, the presence of eggs on bare substrate, and plots of egg distribution relative to gillnets (Figure 2.36) identified these deposits as products of 'forced' spawning by trapped herring.

The dredge Manhattan Island operated in the outer bay within 2.0 to 2.5 km of the Huckleberry-Fox Island complex between late April and May 5 and then moved upriver for about 10 days to avoid interference with the movement of herring schools. However, herring had been in the outer bay since about April 23, and are known to avoid vessel noise (Olsen, 1971). The considerable noise produced by the dredge may have caused avoidance of the Huckleberry Island spawning area while the dredge was nearby. Spawning had occurred in that location by May 5 in 1980 (Pottle et al., 1980).

Turbidity in the outer bay appeared to be worse than in 1980, particularly between Preston Beach and Escuminac wharf, where visibility was occasionally <0.3 m and rarely >1.5 m at 6 m depth. However, turbidity may have been influenced by frequent onshore gales, the Miramichi River discharge, a mid-May bloom of phytoplankton (Thalassiosira sp.), dredging operations, or a combination of these. As noted in previous years, turbidity increased markedly during ebb tides. Despite the apparent high suspended sediment load, there was no noticeable accumulation of sediment on herring eggs or macrophytes between Fox Island and Point Escuminac.



Distribution of herring eggs relative to a fixed gillnet near Escuminac wharf, May 1981. Net position varied with wind, tidal phase, and amount of handling by fishermen.

Figure 2.36

Conclusions

Dredging operations in outer Miramichi Bay were conducted at least 2 km from all known spawning areas and would probably have had no deleterious effects on natural spawning beds, if indeed any were present. Because the dredge was always at least 1.0 km from major concentrations of gillnets, there was probably no significant effect on egg deposits produced by 'forced' spawning. Noise from dredging operations may have caused herring to avoid the Huckleberry Island spawning area prior to May 5. However, little if any natural spawning occurred within the historical area, probably because the fish were unable to penetrate the formidable barrier presented by the high concentrations of fixed gillnets.

If maintenance dredging will be required at the seaward end of the new shipping channel, as indicated by the Miramichi Channel Study (Philpott, 1978), it will be essential to have divers conduct a thorough search for herring spawn on Miramichi Bar if dredging occurs during the spawning season. It is possible that herring that cannot reach the historical spawning area, due to high concentrations of gillnets, may seek alternate sites either in deeper water or at the northern end of Miramichi Bar where depth is $\leq$4 m and substrate and algal cover may be suitable for spawning.

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2.15 PARTITIONING OF HEAVY METALS IN SELECTIVE CHEMICAL PHASES OF DALHOUSIE AND BELLEDUNE HARBOUR SEDIMENTS

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Abstract

A series of chemical extraction methods was used to study the partitioning of Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, and Zn in environmentally sensitive chemical zones in sediment samples of Dalhousie and Belledune Harbours. The data were obtained for the distribution of heavy metals in ion exchangeable fraction, associated with humic and fulvic acids, bound to carbonate, complexed with hydrous oxides of iron and manganese, and chelated to complexing materials in the sediments. In both sediments, significant amounts of metals were found complexed with hydrous oxides of iron and manganese. In other fractions, the concentrations of metals were low. The residual fraction of the sediment contained the major burden of heavy metals.

Introduction

In Dalhousie and Belledune Harbours, sediment concentrations of zinc, lead, copper, and cadmium are considerably higher than natural conditions. The presence of toxic metals, especially cadmium, in sediments in concentrations higher than the 0.6 ug/g limit specified in schedule I of the Ocean Dumping Control Act (1978) poses a problem with harbour dredging. The gross concentration of metals currently employed for evaluating the pollution potential of sediments generally overestimates the status. For Ocean Dumping regulations, Keeley and Engler (1974) considered that fraction of heavy metals in the sediments that has a detrimental effect on water quality and the associated biota. The elutriate test has been designed to measure that fraction of heavy metals which is readily transferred to receiving water. This test does not however take into account long-term effects and the behaviour of heavy metals under changing environmental conditions at a dump site.

In this study, partitioning of heavy metals among various geochemical components of the sediments and their potential effect on the overlying water quality has been investigated. Recently, partitioning of trace metals in sediments of Los Angeles Harbour (Gupta and Chen, 1975), Lake Erie (Walters & Wolery, 1974) and 19 estuaries of south and west England (Luoma & Bryan, 1981) have been studied. Metals partitioned in the ion exchangeable fraction, associated with humic and fulvic acids, bound to carbonate, complexed to oxides of iron and manganese, and adsorbed and chelated to complexing agents in sediments, have been reported. Tessier et al. (1979) have reviewed and discussed the merits of reported methods for extraction of heavy metals from various geochemical phases of sediments. The methods reported by Tessier et al. (1979) and Walters and Wolery (1974) were followed in selective extractions of heavy metals from Dalhousie and Belledune sediments.

Methods and Materials

Sediment samples collected from Dalhousie and Belledune Harbours were homogenized, and a subsample (1 L) was dried 80°C in an air convection drying oven. The dried sample was again homogenized and stored in polyethylene containers.

Metals were analyzed by atomic adsorption (AA) (Perkin Elmer Model 403) and atomic emission (Jarrell Ash Plasma Atom Comp Model 975) spectrophotometric methods. Cadmium was analyzed by the flameless AA method (Perkin Elmer Model HGA2100).

All reagents used in this study were of analytical grade (Baker Analyzed Reagents or Fisher Scientific Co.). All glassware was washed with chromic acid ($K_2Cr_2O_7/H_2SO_4$ 1.2% by weight) and thoroughly rinsed with deionized distilled water before use.

Sediment (0.5 g) was digested with 10 mL HNO_3-HCl mixture (1:3 v/v) in a pyrex glass beaker. The beaker was covered with watch glass and heated to boiling. The heating was continued to near dryness. The process was repeated and then the digestate was washed with 10 mL hydrochloric acid (255) and deionized distilled water to 50 mL.

Sodium hydroxide extract was acidified with hydrochloric acid and heated to dryness on a slow heat. The dried residue was ashed at 450°C for 2 hr in a muffle furnace. The residue was dissolvd in 25 mL HCl (25% v/v) and made to 100 mL volume.

Direct aspiration, methods of standard additions, APDC complexing, and MIBK solvent extraction procedures described in Standard Methods for the Examination of Water and Waste Water (APHA, 1975) were followed. The calibration and performance of the analytical instruments were tested with marine sediment MAG-1 and NBS SRM 1645 river sediment.

Extraction Procedure

A mixture of 10 g sediment and 50 mL extractant solution in a 250 mL volumetric flask was agitated on a wrist action shaker for 2 hr at room temperature. The sediment in the mixture was then allowed to settle down. The liquid layer was decanted, centrifuged, and filtered through 0.45 micron membrane filter paper. The residues were collected and mixed with the bulk in the volumetric flask. The process was repeated twice with fresh aliquots of extracting solutions. The filtrates from the three extractions were mixed and analyzed for heavy metals. The residues were combined and washed with three aliquots of 10 mL deionized distilled water and used for the next extraction. The extracting solutions used for various partitioning phase extractions are listed in Table 2.15.

Results and Discussion

Ion exchangeable metals were depleted by extracting the sediments with 1M $MgCl_2$ solution. Barium, cadmium, and lead were found in this phase in both sediments. Dalhousie sediment contained iron and manganese while Belledune contained a detectable amount of zinc, as shown in Tables 2.16 and 2.17. The metals in this phase are weakly held by Van der Waals, London, and Coulomb forces and easily exchanged with metal ions energetically favoured for these attraction sites. Ion exchange reactions are fast and are important for immediate environmental impacts. This study showed that the metals of direct concern - cadmium, copper, lead, and zinc - were present either in very low concentrations or absent in this phase of the sediments. Detectable amounts of ion exchangeable cadmium and lead were found in both sediments. Humic and fulvic acids in the sediments have

Table 2.15

EXTRACTION PROCEDURES USED FOR PARTITIONING OF HEAVY METALS IN DALHOUSIE AND BELLEDUNE HARBOUR SEDIMENTS

Ion Exchangeable	1M $MgCl_2$
Metals bound to Humic and Fulvic Acids	0.2 N NaOH
Metals bound to Carbonate	0.005 N CH_3COOH pH of the mixture adjusted to 3.5
Metals bound to iron and manganese oxides	2M H_3PO_4 0.05 M $NH_2OH.HCl$
Metals chelated to complexing compounds	0.1% EDTA
Residue and Total	HNO_3 and HCl

TABLE 2.16

SEQUENTIAL EXTRACTION OF METALS - DALHOUSIE HARBOUR SEDIMENTS

Extract		Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
$MgCl_2$	µg/g	6	0.2	-	-	-	4	21	-	2	-	-
1 m	%	9.5	46	-	-	-	-	7.4	-	2.2	-	-
Na OH	µg/g	.3	0.3	-	0.3	3	3	-	-	-	3	-
0.2 N	%	-	7	-	-	10.7	-	-	-	-	8.5	-
CH_3COOH	µg/g	-	-	-	-	-	2	-	-	2	-	-
.005 N	%	-	-	-	-	-	-	-	-	2.2	-	-
pH 3.5												
H_3PO_4-NH_2OH	µg/g	25	0.8	3	27	3	6465	196	2.5	67	17	127
2 m 0.5 m	%	40.0	23	50	59	12.5	24.4	69	17	76	20	20
EDTA	µg/g	1.4	0.1	-	1.3	2	732	7	1.0	5	1	8
0.1%	%	2.2	2.3	-	3	7	3	2.5	7.0	5.7	2.8	1.3
Residue	µg/g	30	2.9	3	17	16	19280	57	11	12	14	498
	%	47.8	67.4	50	37.3	66.6	72.3	20	75.8	13.6	40	78.6
Sum	µg/g	62.7	4.3	6	45.6	24	26486	281	14.5	88	35	633
Total	µg/g	59	5.3	11	39	28	29560	346	42	75	42	600
Sediment		±2	±0.5	±1	±4	±2	±350	±30	±2	±10	±3	±40
Recovery (%)		106	81	55	117	85.7	89.6	81.2	34.5	117	83	106

TABLE 2.17

SEQUENTIAL EXTRACTION OF METALS - BELLEDUNE HARBOUR SEDIMENTS

Extract		Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
$MgCl_2$	µg/g	1	0.2	-	-	-	3	-	-	2	-	2
1 m	%	1	0.3	-	-	-	-	-	-	1.1	-	1.1
Na OH	µg/g	-	0.3	-	-	17	2	-	-	11	5	1
0.2 N	%	-	0.5	-	-	3.7	-	-	-	0.5	8.5	1.1
CH_3COOH	µg/g	-	-	-	-	-	2	-	-	2	-	-
.005 N	%	-	-	-	-	-	1.1	-	-	1.1	-	-
pH 3.5												
H_3PO_4-NH_2OH	µg/g	32	24	1	20	46	5954	125	-	2010	16	1050
2 m 0.5 m	%	34	42	7	43	9	26	48	-	82	33	13.5
EDTA	µg/g	1	0.3	-	1	12	151	3	-	47	1	30
0.1%	%	1	0.5	-	2.1	2.6	0.6	1.1	-	2	1.7	0.4
Residue	µg/g	59	32	13.5	25.5	383	16858	134	15.5	362	27	6686
	%	63.4	56.3	93.1	54.8	83.6	73.4	51.1	100	15	55	86
Sum	µg/g	93	56.8	14.5	46.5	458	22970	262	15.5	2436	49	7769
Total	µg/g	96	54	14	57	428	26224	280	33	2228	59	5100
Sediment		±2	±4	±2	±1	±40	±350	±12	±2	±200	±3	±650
Recovery (%)		96.8	105	103	81.6	107	87.6	93.6	47	109	83	153

a variety of complexing sites to acquire and hold metals in the organic matrix. Oxidation and biodegradation of these organic acids release the trapped metals to surface waters. Decomposition reactions are relatively slow and have long-term effect on the surface water quality. Cadmium, copper, and vanadium were found to be associated with organic acids in both sediments. Barium, chromium, and iron were present only in Dalhousie, and lead and zinc only in Belledune sediments. Although zinc has higher concentrations in both sediments and has similar chemical properties, it was only detected in Belledune Harbour sediment.

Phosphoric acid and hydroxyl amine hydrochloride removed about 25% of total iron from both sites and about 70 and 50% of manganese from Dalhousie and Belledune sediments, respectively. The proportions of iron and manganese extracted during this experiment were high as compared with 7 to 14.4% recorded for south and west England estuary sediments using a mixture of 0.01N HNO_3 and 0.1N NH_2OH HCl (Luoma and Bryan, 1981), and about 10% for Los Angeles Harbour sediments extracted with 25% ACOH and 0.04 M NH_2OH HCl (Gupta and Chen, 1975). Higher buffering capacity of phosphoric acid and chemical forms of metals in Dalhousie and Belledune sediments may be the reasons for greater extracted concentrations. For many metals, phosphate is a very strong complexing agent. It is possible that some of the metal complexed in the sediments was extracted in this phase. All metals investigated in this experiment were found associated with iron and manganese oxides except nickel in Belledune sediment (Tables 2.15 and 2.16). More than 75% of the lead in both sediments resided in this phase. The concentrations of other metals were also high. The behaviour of this section of heavy metals is controlled by the solubilities of iron and manganese. Reducing conditions, created by a micro-organism active in oxidizing organic matter in the sediment, stabilizes iron and manganese to their divalent states. In lower valency states, iron and manganese compounds have greater solubilities and migrate to surface waters. Transfer of these metals to water at sediment surface is accompanied by other associated heavy metals. Since appreciable amounts of lead, zinc, and cadmium associated in Fe and Mg hydroxyoxides can be liberated under reducing conditions, especially from Belledune, the environmental conditions at the dump site will be an important factor in governing the fate of this section of heavy metals.

Heavy metals complexed to chelating compounds in the sediments were extracted with 0.1% EDTA solution. All metals except cobalt in both and nickel in Belledune were found in this phase. The concentrations of metals between 1 and 7% in Dalhousie were higher than 0.5 to 3% in Belledune sediments. The higher concentration of metals may also suggest the higher strength and concentration of complexing compounds in Dalhousie sediments. The fate of this class of compounds depends on the competition of metals for the complexing sites and the decomposition of complexing compounds by micro-organisms at the dump site.

Metals remaining in the sediments are shown as residual metals in Tables 2.16 and 2.17. The data show that major burdens of zinc, copper, and cadmium, the high concentration sediment metals, resided in this phase. In this chemical form the heavy metals in the sediments are expected to be environmentally harmless.

In most of the cases, the sum of sequential extractions of heavy metal was within ±20% of the gross heavy metal concentrations. Nickel in both, and cobalt in Dalhousie fell short, whereas zinc in Belledune exceeded about 50% of the original concentrations noted for these sediments.

Conclusion

Sequential extraction of heavy metals from Dalhousie and Belledune sediments indicates that a major portion of high concentration sediment metals (zinc, copper, and cadmium) resides in the residual fraction of the sediments. The high concentrations of lead were associated with the hydrous oxides of iron and manganese. This phase also contained significant amounts of other heavy metals investigated in this study. This fraction of heavy metals constitutes an important source for release of metals to surface water under reducing conditions. Small concentrations of metals were also found as complexed to chelating compounds in the sediment. However, the concentration of this section of metals was low.

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2.16 A REVIEW OF DISPOSAL ALTERNATIVES FOR DREDGED MATERIALS

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Environmental concern over the state of the world's oceans, as well as a general concern for the overall environment, has led to the declaration of a number of international agreements controlling disposal in the oceans. This process culminated with the London Dumping Convention. As signatories to this convention, many nations, including Canada, enacted legislation and policies to regulate the ocean (i.e., open-water) disposal of dredged materials.

Because, historically, open-water disposal has been the predominant mode for dredged material disposal, many dredging proponents felt that these acts and policies served to restrict open-water disposal in favour of shoreline or land-contained disposal, without an adequate consideration for the economic consequences of these restrictions. The International Association of Ports and Harbours has attempted to bring the problems to the attention of the London Dumping Convention, warning them that such restrictions could eventually cripple many of the world's ports, which are heavily dependent on dredging to maintain access and docking facilities. Tables 2.18 and 2.19 illustrate the worldwide volumes dredged and volumes disposed in the different disposal modes.

Dredging and dredged material disposal has been undertaken for many years in Canada. The need for dredging has resulted from increased commercial traffic in the major ports, an expanding fishing fleet, and alterations in the sedimentation patterns of our rivers and estuaries subsequent to increased settlement and land clearance.

In Canada, as in many other countries, open-water disposal has historically been the predominant mode for dredged material disposal. Many Canadian dredging proponents have felt that the environmental legislative

Table 2.18

Dredged Material Volumes*

(Expressed in thousands of cubic yards)

(from Ad hoc Dredging Comm., Int. Assoc. Port Hbr., 1981)

Region	Maintenance	Construction	Total
Northern Europe	71,516	161,575	233,091
Mediterranean	26	29,395	29,421
Africa	130,773	124,190	254,963
Southern Asia	41,550	243,111	284,661
Southeast Asia	17,473	4,493	21,966
East Asia	6,439	138,337	144,776
South Pacific	7,078	48,524	55,602
North America	27,234	13,640	40,874
Caribbean	640	3,310	3,950
TOTAL	302,729	765,575	1,069,304
	(28%)	(72%)	(100%)

* Maintenance volumes are for the year 1979. Construction volumes represent material dredged during berth and channel construction during the period of 1975 to 1979.

Table 2.19

Method of Disposal

(Volumes in thousands of cubic yards)

(from Ad hoc Dredging Comm., Int. Assoc. Port Hbr., 1981)

Region	Number of Responses	Dry Land	Wetlands	Near Shore	Ocean	Other	Total	
Northern Europe	26	39,196	59,502	42,936	62,044	29,412	233,091	(21%)
Mediterranean	3	0	13,774	15,001	646	0	29,421	(3%)
Africa	2	0	152,942	76,471	25,549	0	254,963	(24%)
Southern Asia	12	62,484	11,197	121,831	89,149	0	284,651	(27%)
Southeast Asia	8	0	3,078	3,698	15,190	0	21,966	(2%)
East Asia	16	5,783	32,220	102,451	4,323	0	144,776	(13%)
South Pacific	18	3,972	2,687	16,355	32,588	0	55,602	(5%)
North America	18	6,012	9,696	8,459	16,549	159	40,874	(4%)
Caribbean	5	820	646	0	2,484	0	3,950	(1%)
TOTAL	108	118,267 (11%)	285,742 (27%)	387,202 (36%)	248,522 (23%)	29,571 (37%)	1,069,304	(100%)

acts and policies served to restrict open-water disposal in favour of containment area disposal, either shoreline or land, without an apparent equal consideration for the economic or environmental consequences of these restrictions. At first, a rather adversarial approach was taken by both the dredging proponents and the environmental regulatory agencies; however, as both sides have achieved a better understanding of the other's problems, restrictions, and goals, a better working atmosphere has been achieved. But there are still some serious problems existing in the review of dredged material disposal in Canada.

As a result of these problems and concerns, three major Canadian dredging proponents, Public Works Canada, Transport Canada, and National Harbours Board, contracted with MacLaren Plansearch/Lavalin to conduct a review of disposal alternatives for dredged materials. This review was divided into two components: policy and technical. The policy component was a review of legislation and policies applicable to dredged material disposal. The technical component served to review and to outline for a dredging project manager the various components that must be considered for a project, the applicable chemical, physical, and biological criteria, the reasons and pitfalls of these criteria, and suggested procedures that a manager might follow. The following report is a summary of the conclusions and recommendations of this study.

Primary among the problems is the need to place all review criteria on an equal footing and, as a corollary to this, to consider all disposal alternatives equally. The concept of implementing the Environmental Assessment Review Policy (EARP) by the federal government was to bring environmental considerations (environmental protection and socio-economic) into the criteria used to review a project. However, the accompanying body of laws and policies implemented subsequent to EARP tended to place environmental protection concerns higher in a priority list than other concerns. There is a need to re-organize project review criteria so that socio-economic, as well as environmental protection, criteria are considered.

In many instances the dredging proponent can be faulted for not presenting a more complete case study to environmental review agencies. Several regulatory/review agencies indicated that they often received the barest amount of information on which to base a decision, and implied that in some cases a different decision may have been reached if more information had been forthcoming.

A second major problem that exists, more in theory than in practice, is the plethora of laws, policies, and overlapping jurisdictions applying to dredged material disposal. The problem is less in practice, only because of the development of good working relationships between various regulatory agencies. In many cases, particularly marine projects, the environmental laws and the groups reviewing these laws are different for each disposal mode. Less confusion might result for the proponent if a dredged material disposal review committee was designated within regulatory agencies, so that all modes of disposal were equally considered. A reasonable codification and uniformity of guidelines (not specific criteria) with regard to all dredged material disposal is needed.

A third problem lies with assessment procedures for both freshwater and marine projects. Because open water has been the historically predominant disposal mode for non-usable materials (i.e., not sand and gravel for construction/engineering purposes), much of the review criteria have been developed for this disposal mode. There is a need for both proponents and regulatory agencies to assess dredged materials in such a way that all disposal modes are equally considered with part of this review to include the economics of the disposal options.

Parallel to the problem with assessment procedures is the problem of assessment criteria. Two questions are often posed to the dredging proponent:

(a) What is the chemical distribution of a select group of constituents? and

(b) Are these constituents available to the biota such that a deleterious impact at a disposal site can occur?

The development of specific numerical criteria to answer question (a) has often obscured the importance of question (b). Existing review procedures appear to attempt to answer the question of bioavailability by determining the chemical concentrations of constituents. However, chemical concentrations, or even distributions, are only a partial answer to bioavailability.

Our technical survey of existing environmental criteria indicate that, in the past, an over-reliance has been placed on bulk chemical analysis of dredged materials. A major fault has been the implicit assumptions that all of a constituent is equally available and that the physico-chemical environment does not affect the chemical reactivity of the constituents. A large number of scientific studies indicate that these assumptions are basically wrong. The bulk chemical technique may be a cheap screening tool, but it should be considered just that, a screening tool. Once a material has been assessed as being 'contaminated' on this basis, a further, more in-depth assessment should be conducted where the assessment reviews and considers equally all disposal alternatives for a project.

However, even after the 'best' disposal alternative has been chosen, a problem that often arises in projects is the limitation because of the disposal alternatives due to the available dredging fleet limitations. There is little to be gained by advocating specialized open-water disposal operations, such as 'capping,' if the existing fleet has neither the capabilities nor the experience to conduct these procedures. An upgrading of Canadian equipment and expertise will probably have to occur, so that such disposal operations can be undertaken.

Although some changes may be forthcoming in the way projects and disposal options are reviewed, the environmental component of a review process will always be an important element. Therefore, it is incumbent upon a project manager to recognize all of the elements necessary in a project review and schedule his project accordingly. Good planning must include an appreciation of all facets of a project, not just the contracting and operational components.

2.17 ASSESSMENT OF SAINT JOHN HARBOUR DUMP SITE (STATUS REPORT)

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Statement of Work

To determine:

(a) if the benthic biota differs appreciably from that in a nearaby similar (control) area, and

(b) if levels of heavy metals, PCBs, and PAHs in the organisms from the dump site area differ appreciably from those in organisms from the control area (heavy metals include Hg, Cd, Pb, Zn, and Cu).

Four sites on and near the Saint John Harbour dredge-spoils dumping ground off Black Point were sampled on October 13 and 14, 1981. Two stations were located on the dumping ground proper, one control station was 950 m east-northeast of the dumping ground toward Deep Cove but away from Canaport, and a second control station was established 1760 m north of the dump site, nearer the harbour. Both because a suitable Smith-McIntyre or Van Veen grab was not readily available, and because it was thought desirable to attempt to reduce major differences between station substrate characteristics, sediments at all stations were inspected and then sampled by a diver using an air-lift dredge equipped with a collecting bag of 1 mm^2 mesh. At three of the four stations, five replicate samples were collected from within a 0.25 m^2 sampling frame to a depth of 7.5 cm. Only 3.5 replicates could be collected at one of the dump-site stations due to a combination of low air reserves and deteriorating weather, currents, and underwater visibility.

Organisms have been sorted and identified from all replicates collected. Polychaetes, crustaceans, and molluscs are predominant, in that order. Dump-site stations were characterized by a scoured, compacted sandy-clay or sandy-gravel substrate, and had relatavely sparse faunas. One of these stations was populated by only six taxa among five replicates;

the other, by ten taxa among three replicates. The majority of species collected at dump-site stations were represented by only one individual per station. In contrast to this, 12 taxa were found in samples collected at the control station 0.95 km east-northeast of the dumping ground, and the numbers recovered for each species were generally greater than at the dump-site stations. The substrate at this station was somewhat less compacted gravelly-sand. At the control station 1.76 km north of the dumping ground the fauna was quite diverse, totalling 31 taxa among the five replicates collected. Twenty-two of these taxa were exclusive to this station, and most species were represented by several specimens. Substrate characteristics varied considerably between replicates, from predominantly gravel to mud-clay.

It is apparent then that the benthic fauna at the Saint John Harbour dump site is slightly depauperate relative to that at the control station 0.95 km to the east-northeast, and very depauperate relative to that at the control station 1.75 km to the north. The degree of significance that can be accorded these results awaits the completion of an analysis of variance. We suspect, however, that these differences are largely functions of bottom current velocities and substrate instability and/or compaction, and that they are probably not attributable to local concentrations of heavy metals, PCBs, or PAHs at the dump site. It should be recalled that the high heavy-metal anomalies reported by D.H. Loring in 1979 were near but off shore from the dump site.

Unfortunately, the organism biomasses collected at all stations in the present study were much too low to permit reliable chemical analyses being performed. Instead, replicate samples of sediment returned from each station have been sent to the chemistry laboratory at the Research and Productivity Council in Fredericton, but the analysis results have yet to be submitted to us. If sediment concentrations of PAHs, PCBs, and heavy metals at the dump site prove to be little or no higher than those at the control sites, they and our underwater observations should lend suport to the commonly-held notion that dredge spoils dumped off Black Point are

rapidly transported elsewhere by a strong seaward bottom current. That this would happen was, of course, the rationale for moving dumping activities to the present location in the first place.

3. PANEL AND GROUP DISCUSSIONS

3.1 Panel Discussion - Land versus Ocean Disposal for Contaminated Sediments

Day 2 of the workshop was given over to discussion of problems and research needs in the ocean dumping of dredged materials. In brief introductory remarks, Alan McIver (RODAC Acting Chairman) noted that, on day 1 of this workshop, scientists had told environmental managers about their problems and concerns, and that today's discussions would mainly focus upon managers' problems in implementing ocean dumping legislation so that scientists would have a clearer understanding of questions requiring resolution and an opportunity for input to the management process.

P. Eaton, EPS, Dartmouth, chaired the session and introduced the panel for discussion of:

Land Versus Ocean Disposal for Contaminated Sediments.

Each panel member gave a brief outline of his views and interactions with the discussion topic.

I. Travers, EPS, Dartmouth, noted that the EPS Hazardous Wastes Section is primarily involved in the disposal of hazardous wastes; however, the section occasionally inherits problems related to dredged material disposal when an Ocean Dumping Permit is denied for material containing substances in concentrations exceeding Ocean Dumping Control Act Schedule I limits. This situation is a problem since material volumes are generally large and in most cases commercial landfill operations will not accept contaminated dredged material due to its high water content and the contaminants it contains. The result of this situation is that in most cases completely new sites must be found, and this requires that factors such as ground and surface water characteristics, public reaction, land ownership, long-term site maintenance and monitoring, revegetation, and Provincial jurisdiction be addressed. I. Travers noted that there are presently no Canadian guidelines for landfill sites and that the Hazardous Wastes Section has been generally referring to United States EPA

guidelines. Recent experience with the containment of contaminated dredged material from CFB Halifax at the Bedford Magazine Hill site has been less than satisfactory. The disposal operation cost $350,000 and monitoring of wells around the site has indicated increasing groundwater chloride levels which may be the initial stage of leaching from the site. It was stressed that the main concerns of the Hazardous Wastes Section of EPS relate to human health problems, particularly in groundwater and surface water.

D. Loring of the Bedford Institute of Oceanography (BIO) noted that there has been great pressure to continue ocean dumping. In general, it may be best to dump ocean sediments in an ocean environment because land disposal exposes sediments to a land/air environment, making the contaminants unstable and subject to leaching. He emphasized that research should try and identify places in the marine environment where the wastes can be disposed of while maintaining a chemical equilibrium.

Glenn Duncan, Marine Directorate, Public Works Canada (PWC), stated that his department did not always look to open-water disposal as the only option and that it did use land disposal extensively in the Great Lakes area. One of their primary concerns was cost, with dyked land disposal costing about $\$20/m^3$ compared to approximately $\$3/m^3$ for open-water disposal. PWC examines a range of solutions for each site based on contamination of the sediments. In cases of contaminated sediments they have reviewed several options including capping or dumping in an already contaminated area. He noted that they (PWC) were not introducing contaminants or causing the problems, but were only the recipients. One could not expect to make PWC responsible for environmental cleanup.

D. Scarratt, of the Fisheries and Oceans Marine Biological Station at St. Andrews, N.B., noted the question of disposal was really a question of which marine resource was more important (i.e., commercial shipping or fisheries). He pointed out that at present cost-benefit analyses which result in a perceived low cost of ocean dumping do not consider the costs of the impact of disposal on local fisheries. It was suggested that dredged spoil should be looked upon as a resource, and material be made available for operations such as infilling for wharf construction as

in the case of Saint John Harbour. A much longer term (10 to 20 yr) holistic approach to dredging and port development could provide the time required to dewater such material. Cost benefit studies should not consider strictly the costs to a principal proponent and there is an urgent requirement to develop a method whereby costs to fisheries may be quantified.

D. Bezanson, Coastal Oceanography, BIO, noted that there is a strong physical argument for land disposal. Since most dredged harbours are at the heads of estuaries, the dumping of spoil at the mouth of the estuary may place the material into the estuarine bottom water return flow, and the material in some cases will eventually return to the head of the estuary from where it was removed in the first place. He was also concerned that contaminants may become unstable in the new environment at a dump site. A preferred option in such cases would appear to be nearshore disposal at the head of an estuary, behind berms if necessary. Harbour design should emphasize self-dredging of harbour facilities by increasing tidal current flows at dockside thereby reducing maintenance dredging requirements. A much longer term (10-20 yr.) approach to dredging and port development is needed to address the broader issue of what the most beneficial and environmentally acceptable management plan might be.

In the ensuing discussion between members of the panel and the audience, many diverse points of view were aired. Some of the more common points are outlined below.

It was pointed out that often a noncontaminated ocean sediment may be considered as contaminated for land disposal due to the salt water content. Land containment is also generally very messy and odorous, being unsightly for a long period of time. In general, it is possible that by reducing an ocean impact the environmental impact on land could be worse.

G. Duncan's reply to comments regarding consideration of the use of dredged material as a resource indicated that PWC considers this approach where applicable; however, this approach is not always possible

since some material requires up to 20 years to dewater to the point where a containment site is usable for construction. He also questioned the philosophy that harbours should be designed to incorporate flushing and wondered what the difference is between long-term ocean disposal of contaminants by this process versus the short-term aspects of dredging and disposal.

Much of the discussion noted the common-resource (i.e, fishery) impact of ocean disposal opposed to more specific land-disposal impacts. It is very difficult to cost ocean-disposal impact or assign responsiblity for contamination of sediments, except in a few specific instances. Holistic, rather than compartmentalized, planning is required to assess industrial expansion. The ultimate decision on which disposal method to adopt must include economic and political perspectives as well as environmental considerations. In Atlantic Canada there is always a conflict between economic viability and pollution control. However, the long-term solution is to control pollution at source.

In summary, many problems in contamination and disposal occur, and specific regional problems exist in relation to Hg, Cd, and Pb contamination. A broader view of development is required to replace the present emphasis on specialized studies with fairly narrow terms of reference.

3.2 Group Discussion - Directions for Research into Disposal Problems at Dalhousie, N.B.

This informal open discussion was chaired by A. McIver who reviewed dump site locations noting that open water disposal had ceased in 1978 and that dumping had been carried out in nearby West Bay.

It was noted that ocean disposal of dredge spoils from Dalhousie may not be appropriate because cadmium is present in concentrations exceeding Schedule I limits. The cadmium has not been shown conclusively to be nonavailable to biota. Also questions exist as to the stability of Heron Island dump site and wood wastes present in the spoils may be the cause of fishermen's net fouling problems. The overall solution is to stop the input of metals and wood wastes at source and considerable progress has been made in this regard.

Various suggestions for capping trials and more study of the geochemistry of Cd were presented. The inconclusive nature of data derived from previous bioaccumulation studies was noted. A further comment on past and proposed studies emphasized that the approach had been piecemeal and that a re-assessment of the questions being asked is required.

G. Duncan suggested that an experimental capping program be conducted using the cadmium-contaminated dredge spoils from Dalhousie Harbour and he indicated, since costs would obviously exceed funding available through the Ocean Dumping Research Fund, that PWC would be prepared to fund such an undertaking. The response to this by scientific and regulatory representatives was generally favourable; however, based on experiences with the Miramichi Channel dredging monitoring program doubts were expressed as to whether a PWC administered scientific study would provide data suitable for scientists to interpret and regulatory agencies to make decisions on. It was suggested that any capping study funded by PWC be jointly administered by RODAC or its designates to ensure that the funds provided result in the most useful scientific information possible being collected. G. Duncan agreed with that approach.

At the end of the discussion the list of research topics presented below was drawn up. This list is not necessarily in order of priority.

Dalhousie research priorities

(1) Test capping and monitoring
(2) Resolve conflicting Cd bioaccumulation conclusions
(3) Change in states of Cd which occur over time and relation to organic matter concentration and degree of oxygenation
(4) Investigate association between Cd and degrading wood fibres
(5) Search for an area suitable for capping experiment
(6) Ecological implications of capping
(7) Study land-fill technology
(8) Upgrade scientific knowledge on Pb and Zn
(9) Improve understanding of physical behaviour at Heron Island dump site

3.3 Group Discussion - Directions for Research into Disposal Problems at Saint John Harbour, N.B.

This informal open discussion was again chaired by A. McIver. Introductory remarks were made by Dr. D. McLeese concerning ongoing work (see Assessment of Saint John Harbour Dump Site).

Initial discussions compared Saint John Harbour to Dalhousie or Belledune Harbours. The harbour is relatively clean with regard to metals and the physical oceanography is fairly well understood. It was noted that in a recent workshop most of the available information had been presented and the information gaps were not as critical as in the case of Dalhousie.

Questions were raised concerning reduced water depth at the existing dump site, due possibly to dumping of gravel during construction of the Rodney terminal. Questions were also raised concerning whether sediments were or were not being winnowed away from the dump site.

Attention was focussed on port development plans and requirements for new dredging, especially in Courtenay Bay. Land disposal or nearshore options were discussed and the point was again raised that a broad-based or holistic view of port development should be taken. Transport Canada has reportedly undertaken a development study.

In general, it was concluded that the level of information on sediments in Saint John Harbour was at present adequate, although an overall port development plan is required. There is also a requirement to re-assess the Black Point dump site and its suitability for possible large scale port development in the future.

Saint John Harbour research priorities

(1) Can the existing disposal site assimilate increasing material volumes?

(2) Determine whether it is more desirable to have materials transported away from the dump site into the Bay of Fundy or whether a more stable site is required.

(3) Obtain a long range plan for port development.

(4) Look at disposal alternatives.

3.4 National Ocean Dumping Research Priorities

Mr. Buxton's informal presentation reviewed the National Committee's perspective on ocean dumping problems as identified by the regions.

The first topic was the ODCA Research Fund and its application to research needs. The fund is to provide information on three main areas of concern:

(1) General scientific information to assist RODAC,

(2) Appraisal or development of policy/regulations, etc.,

(3) Assessment of long-term effects of pollution.

The factors taken into consideration in addressing these concerns and assigning overall priorities recognize both regional and national needs. In summary, they are:

i. ongoing research (currently funded)

ii. regionally identified research priorities

iii. international research needs identified via the London Dumping Convention (LDC)

iv. alternative proposals and relative merits

v. economic considerations (cost of proposal versus availability of funds)

vi. potential contribution to preservation of common heritage/marine environment

The Arctic has been identified as a special research area because of the rate of development and the relative lack of environmental data upon which to base sound environmental judgements. Another major problem is overlap in submissions for funding resulting from a general lack of knowledge of ongoing work in other Regions.

Mr. Buxton then described the recent submission to Treasury Board, which requested that ODCA research funds be increased to $300,000 (compared to $180,000 last year). He noted that the funding level has been frozen for the last six years while permit applications had risen from 100 to more than 200 per year and inflation had eroded significantly the research purchasing power of the fund. Funding has been inadequate for EPS

to monitor all significant dump sites or carry out research program effectiveness reviews. The types of monitoring required were described as follows:

a. general surveillance monitoring
b. scientific research monitoring
c. monitoring for dump-site selection and sensitivity mapping
d. permit evaluation monitoring
e. inspection/enforcement monitoring

At the annual ODCA program manager's meeting overall research priorities are identified to facilitate research proposal submission prior to the next fiscal year. The conclusions of the program managers' review on ocean dumping research this year were:

I. A better definition of research needs on a program basis (i.e., not so site-specific) is required,

II. Regional identification of questions which require answers via research projects,

III. Priority should be given to publishing (defining what is known to date and areas others are currently working in).

The basic need at the program manager's level is a better overview and a less site-specific approach.

Identified national priorities were very simlar to those identified at this workshop and in other regions. These were as follows,

National priorities

(1) program summaries and publications,
(2) resolution of dump-site problems (e.g., Cd),
(3) analytical methodologies, standardization, and quality assurance,
(4) waste disposal impact assessment, and
(5) alternative disposal techniques (e.g., capping).

In regard to the Act itself, Mr. Buxton noted a lack of scientific data to support existing regulated levels of contamination and that also there was no scientific basis for change. He noted that managers need good scientific data from research to provide a rational basis for management of ocean dumping.

Brief discussion followed noting that there was no well known report series for RODAC. It was pointed out that there was in fact a RODAC report series but only three volumes have been published. Most reports come out under other covers. It was suggested that ODCA funded reports be re-issued under RODAC covers, where possible and practicable.

3.5 Regional Perspectives on Ocean Dumping Research Priorities

A brief discussion emphasized that most of the problems on a program basis had been already discussed. On a site-specific basis Dalhousie was a problem area; other areas of interest were Miramichi and Saint John Harbour.

Analytical methodology was again highlighted. Some opinions on Cd concentrations indicated analyses may be out by an order of magnitude. If concentrations are not known accurately, rational management decisions cannot be made.

The problem of getting information public was raised again and note made of the delay in getting previous workshop information published.

APPENDIX 1
LIST OF WORKSHOP ATTENDEES

V. Buxton, EPS/DOE, Ottawa, Ontario.
D. Buckley, AGC/EMG/BIO, Dartmouth, N.S.
D. Bezanson, OSS/BIO, Dartmouth, N.S.
B.B. Bernstein, Welsford Research Group, Halifax, N.S.
D. Brothers, EPS/Pacific/Yukon Region, West Vancouver, B.C.
T.R. Bradley, Transport Canada, Dartmouth, N.S.

J. Carter, Martec Ltd., Halifax, N.S.
R. Cranston, AGC/EMG/BIO, Dartmouth, N.S.

G. Duncan, DPW, Ottawa, Ontario
P. Dunham, Geomarine Associates Ltd., Halifax, N.S.
C. Duerden, EPS, Dartmouth, N.S.

P. Eaton, EPS/Atlantic, Dartmouth, N.S.

A. Feicht, Atlantic Analytical Ltd., Saint John, N.B.
D. Frobel, AGC/EMG/BIO, Dartmouth, N.S.

R. Guevremont, NRC, Halifax, N.S.
R. Gershey, NRC, Halifax, N.S.

H. Hall, EPS Atlantic, Dartmouth, N.S.
H.H.V. Hord, DFO, St. Andrews, N.B.
V. Hawkins, EPS Atlantic, Dartmouth, N.S.

M. Hawco, Shawmont Nfld. Ltd., St. John's, Nfld.
M. Hutcheson, MacLaren Plansearch, Dartmouth, N.S.
S. Hughes, EMG/BIO, Dartmouth, N.S.

T. Kendaris, Dobrocky Seatech (Nfld.) Ltd., St. John's, Nfld.

W. Lord, DPW, Saint John, N.B.
D.H. Loring, OSS/AOL/BIO, Dartmouth, N.S.
E. Lewis, NRC, Halifax, N.S.

A. McIver, EPS, Dartmouth, N.S.
S. MacKnight, MacLaren Plansearch, Dartmouth, N.S.
C. MacGregor, Seatech Investigation Services Ltd., Halifax, N.S.
J. MacKay, DPW/Rep. P.E.I., Charlottetown, P.E.I.
T. MacPherson, N.S. Environment, Halifax, N.S.
D.W. McLeese, DFO, St. Andrews, N.B.
D. Milburn, EPS, St.John's, Nfld.
B. Mosher, DPW, Halifax, N.S.
C. Murphy, P.E.I. Environment, Halifax, N.S.
S.C. Murphy, P.E.I. Dept. of Comm. Affairs, Charlottetown, P.E.I.
L.E. Muzzatti, Canadian Coast Guard, Dartmouth, N.S.

H. Nelson, EPS/Pacific/Yukon Region, West Vancouver, B.C.
M. Northcott, Dept. of Oceanography/Dal. Univ., Halifax, N.S.

C.W. O'Leary, Transport Canada, Dartmouth, N.S.

G. Packman, EPS, Dartmouth, N.S.
R. Parker, EPS/BIO, Dartmouth, N.s.
F. Perron, EPS/Quebec Region, Montreal, Que.
G. Pope, Beak Consultants, St. John's, Nfld.
S. Ray, DFO, St. Andrews, N.B.
D.C. Riley, DFO/FMM, Halifax, N.S.
R.T. Rantala, OSS/AOL/BIO, Dartmouth, N.S.

C.J. Spencer, EPS, Dartmouth, N.S.
H. Samant, EPS/BIO, Dartmouth, N.S.
D.J. Scarratt, DFO, St. Andrews, N.B.

K.L. Tay, EPS, Dartmouth, N.S.
O. Vaidya, EPS Atlantic, Dartmouth, N.S.
D.J. Wildish, DFO, St. Andrews, N.B.
G.F. Westlake, EPS Atlantic, Dartmouth, N.S.

D. Yurick, Marine Research Assoc., St. Andrews, N.B.

APPENDIX 2
OCEAN DUMPING RESEARCH FUND

1. 1980/81 PROJECTS

(i) S. Ray and D.W. McLeese. Study of bioavailability of cadmium and lead from sediment through food chain uptake by selected marine invertebrates.
Ocean Dumping Research Fund: $12,600

(ii) D.J. Wildish and S.N. Messieh. Effect of ocean dumping on the Miramichi Bay herring fishery.
Ocean Dumping Research Fund: $35,000

(iii) C. Schafer. Benthic survey of Heron Island dump site.
Ocean Dumping Research Fund: $18,000

(iv) R.W. Elner. The effect of sediment on the behavior of the American lobster - Homarus americanus.
Ocean Dumping Research Fund: $10,000

(v) K.L. Tay. A literature review of lead and its compounds in the marine environment.
Ocean Dumping Research Fund: $1,000

(vi) Environmental Protection Service, Newfoundland. Chemical analysis of biological samples from an ocean dump site at Fermeuse.
Ocean Dumping Research Fund: $2,400

2. 1981/82 PROJECTS

(i) S.N. Messieh. Impact of dredge spoil disposal on the Miramichi Bay herring fishery.
Ocean Dumping Research Fund: $22,000

(ii) G.A. Packman, D. Bezanson and K.L. Tay. Bay of Chaleur dump site studies.
Ocean Dumping Research Fund: $10,000

(iii) D.W. McLeese and S. Ray. Assessment of Saint John Harbour impacts of dumping at the Black Point dump site.
Ocean Dumping Research Fund: $14,000

(iv) S. Ray and D.W. McLeese. Bioavailability of cadmium and zinc from lead and zinc concentrates.
Ocean Dumping Research Fund: $15,000

(v) R.W. Elner. Investigation into the direct and indirect effects of ocean dumping on lobster ecology and habitat.
Ocean Dumping Research Fund: $7,500

(vi) D. Scarratt. Analysis of stomach contents of smelt from the Miramichi River estuary.
Ocean Dumping Research Fund: $5,500

(vii) D.J. Wildish. Analysis of avoidance behavior of smelt, tomcod, and gaspereau in Miramichi dredge spoil plumes.
Ocean Dumping Research Fund: $5,500

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